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This document presents a review of the often contradictory literature describing the effects of release waters on the tailwater environment and biota. The physical and chemical conditions found in tailwaters downstream from warmwater and coldwater discharge impoundments are compared and contrasted to those found in natural streams.

Reservoir discharges modify the physical, chemical, and biological

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characteristics of the stream ecosystem. Physical and chemical characteristics in tailwaters are primarily determined by the depth, volume, and schedule of water releases. The magnitude of change is related to the type of reservoir and to the design and operation of outlet structures.

The structure of the biotic community reflects the physical and chemical conditions existing in a particular tailwater. The community is composed of organisms, including nonnative species, that are adapted to this environment. The effects of the tailwater environment on the life history, physiology, and abundance of selected species are described.

This information will aid in the development of reservoir discharge guidelines that will enhance the quality of the tailwater environment to increase project benefits.

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PREFACE

This report was prepared by the U. S. Department of the Interior, U. S. Fish and Wildlife Service, National Reservoir Research Program (NRRP), East Central Reservoir Investigations (ECRI), Bowling Green, Ky., with the assistance of the Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES), under Interagency Agreement WES 79-04 dated 1 April 1980. This study forms part of the Environmental and Water Quality Operational Studies (EWQOS), Task IIB, Reservoir Releases. The EWQOS Program is sponsored by the Office, Chief of Engineers, and is assigned to WES under the management of EL.

This report was written by Messrs. Charles H. Walburg, Jerry F. Novotny, Kenneth E. Jacobs, William D. Swink, and Terry M. Campbell of ECRI and Drs. John M. Nestler and Gary E. Saul, EL, WES. Mr. Charles H. Walburg is the Chief of ECRI, and Mr. Robert M. Jenkins is the director of the NRRP.

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The Commander and Director of WES during this study was COL Nelson P. Conover, CE. The Technical Director was Mr. Fred R. Brown.

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CONTENTS

EFFECTS OF RESERVOIR RELEASES ON TAILWATER ECOLOGY: A LITERATURE REVIEW

PART I: INTRODUCTION

Problem

1. The Corps of Engineers (CE) normally operates reservoir projects to achieve downstream environmental quality objectives consistent with project purposes. Presently, there are no quantitative approaches or reliable guidelines for determining water releases necessary to ensure the maintenance of a desired downstream aquatic environment. Many environmental quality requirements for downstream habitat and biota are not well understood or substantiated.

2. Reservoirs affect downstream aquatic habitats in a number of ways, depending on project design and operation and specific environmental requirements of downstream biota. Large variations in flow associated with power-peaking operations may adversely affect downstream fisheries during spawning periods, disrupt benthic communities that serve as food for fish, and limit stream recreation. Changes in temperature, dissolved gases, and other water quality characteristics associated with reservoir releases greatly influence the species composition and abundance of the tailwater community.

3. The operation of reservoirs to achieve desired downstream objectives is often complicated by conflicting requirements to improve in-lake water quality or demands of other project purposes. Periodically, minimum releases required to maintain downstream aquatic habitat and associated stream recreation are greater than the releases required to meet other authorized project purposes. During these periods, problems associated with reservoir releases often become critical. Since the benefits of maintaining or enhancing downstream aquatic habitat and biota are difficult to quantify, justifying the allocation of reservoir storage for downstream releases is complicated. Nevertheless, minimum releases are required to maintain adequate downstream habitat.

Study Approach

4. The first task of the U. S. Fish and Wildlife Service in preparation of this report was to conduct an exhaustive literature search on the effects of reservoir water releases on tailwater biota. An annotated bibliography was prepared from the literature that most directly concerned tailwater problems (Walburg et al. 1980).

5. This report reviews available literature on the effects of reservoir releases on tailwaters that support populations of warmwater fish or trout. The extensive literature available on anadromous fish is not included. This "state-of-the-art" report documents the relation between changes in the quantity and quality of reservoir water releases and the quality of the downstream aquatic environment. The review also includes selected stream and river studies that have application to tailwater problems. Tailwaters cited in this report are listed alphabetically in Appendix A together with name of river and location (e.g., state of the United States or country). The geographic locations of the 106 tailwaters located in the United States are shown in Appendix B (Figure B1).

6. To better understand the physical and chemical conditions found in tailwaters, this report begins with a brief description of reservoir limnology, followed by a section on the design and operation of reservoir outlet structures and how this can impact the tailwater environment. This is followed by a review of the physical, chemical, and trophic conditions found in tailwaters. A general review of invertebrate ecology in both streams and tailwaters is then presented. Life history requirements of fishes found in tailwaters are reviewed, together with a description of their response to the tailwater environment. Tailwater environments created by various management schemes for reservoirs and tailwaters are discussed generally. Major physical and chemical alterations are indicated, together with descriptions of how they affect organisms of the higher trophic levels. Finally, the nature and scope of studies necessary to complete the development of conceptual models that can be used to predict the effect of changes in reservoir management on the tailwater environment are indicated.

PART II: BASIC RESERVOIR LIMNOLOGY

7. Knowledge of reservoir limnology is fundamental to understanding water quality characteristics in tailwaters. Water quality in reservoir changes with season. The extent of change reflected in the tailwater depends on the depth of water withdrawal, project design, morphometry of the tailwater channel, and local atmospheric conditions. The following brief overview of reservoir limnology is intended to provide sufficient background information for a biologist or engineer to understand the relationship between reservoir biogeochemical processes and tailwater ecology; it is not intended to be a detailed discussion of limnology. For a comprehensive description, the reader should refer to the works of Hutchinson (1967), Wetzel (1975), and Cole (1975).

Hydraulic Residence Time and Settling within Reservoirs

8. In general, reservoirs with short hydraulic residence times have a reduced impact on tailwaters because the water is discharged before the effects of impoundment become established. This type of reservoir is often termed a flow-through or run-of-the-river project. The discharge is usually similar to the inflow in oxygen concentration, temperature, turbidity, and nutrient concentration. Reservoirs with long hydraulic residence times undergo processes somewhat similar to those observed in lakes, although there are significant differences (Neel 1963; Baxter 1977).

9. Reservoirs with long hydraulic residence times act as settling basins in which suspended particles settle from the water column. They are effective in removing suspended material from inflowing streams or sediments washed into the reservoir during summer rains. Turbid water is usually discharged into the tailwaters only after long winter rains that are accompanied by high runoff rates (Churchill 1967).

Thermal Stratification

10. The process of thermal stratification is a major factor in altering the water quality of reservoirs. An understanding of thermal stratification and its influence on water as it flows through a reservoir is essential to discussion of water quality in tailwaters.

11. Reservoirs stratify thermally when solar radiation and inflows from warmer tributaries during the spring heat surface waters more rapidly than the heat can be distributed throughout the water column. This produces temperature and density differences between the surface water and the underlying water, increasing the resistance to mixing. Shearing between the surface and deeper waters inhibits additional mixing and results in the formation of an upper layer of warm water (epilimnion) and a deep layer of cold water (hypolimnion), with a transitional layer between the two (metalimnion). Following stratification, mixing effects caused by wind and air temperature changes are largely limited to the epilimnion.

12. Reservoirs destratify thermally when the loss of heat to the cooler atmosphere in late summer and early fall exceeds the heat input from solar radiation. Complete thermal mixing begins when the surface water cools and becomes as dense as the deeper water. Eventually the entire water column loses its resistance to mixing and the reservoir becomes thermally uniform (Wetzel 1975). Tributary inflows may accelerate destratification by providing additional cool water.

13. The water column in warm temperate reservoirs is essentially of constant density during the winter, and little thermal resistance to mixing occurs. Convection currents and relatively little wind action can thoroughly mix the entire water column (Churchill 1967). As a result, the chemical and physical characteristics of the water remain uniform throughout the reservoir until spring. These reservoirs are termed monomictic, since they circulate freely only during the winter months.

14. Reservoirs in cooler temperate regions may become stratified during the winter. The coldest water (0-3°C) remains at the surface

and the warmer, most dense water (4°C) sinks to the bottom (Wetzel 1975). These reservoirs are termed dimictic because they circulate freely twice during the year following spring and fall destratification.

15. Not all reservoirs thermally stratify during the summer. Shallow reservoirs with relatively rapid rates of flow-through and exposure to extensive winds usually remain vertically mixed. Temporary temperature "differences" which form after extended periods of calm weather and reduced discharge may be destroyed by wind action. These reservoirs may, however, undergo periods of winter stratification after ice cover formation.

Dissolved Oxygen

16. Concentrations of dissolved oxygen in reservoirs are closely associated with the stratification process. In stratified reservoirs, the epilimnion is well aerated due to wind action, mixing resulting from diurnal temperature fluctuation, and oxygen produced during photosynthesis. Dissolved oxygen in the hypolimnion, however, is limited to that available at the time of stratification, and may be reduced or eliminated by the oxidation of organic matter that settles into the hypolimnion from the epilimnion. These conditions persist until the reservoir mixes vertically. Low dissolved oxygen concentrations are seldom a problem during the winter, when low water temperatures suppress metabolic activity, and oxidation rates of organic compounds are reduced. However, low dissolved oxygen can occur in ice-covered lakes during the winter with resultant fish kills.

17. In unstratified reservoirs, complete circulation and frequent aeration by wind action ensures that adequate oxygen is available throughout the water column. Low oxygen concentrations may occur in localized protected embayments and other areas not subject to frequent circulation. Also, nighttime algal respiration may lower oxygen levels.

Nutrient Concentration

18. The import of nutrients from upstream or watershed runoff is

the main source of reservoir enrichment. Maximum inputs generally occur after heavy rains. Excessive amounts of nutrients (e.g., from municipal and agricultural sources) can cause deterioration in overall water quality. Nutrients can also be released from the sediments under anoxic conditions. These nutrients can be carried to the surface during lake turnover. In addition, wind-driven currents can incorporate sediments and associated nutrients into the water column in shallow, unstratified reservoirs.

19. Phytoplankton growth is stimulated by an influx of nutrients. In stratified reservoirs, phytoplankters continuously settle out of the epilimnion into the hypolimnion. The loss of nutrients from the epilimnion resulting from settling may limit further phytoplankton production, whereas, the hypolimnion becomes increasingly enriched as the accumulation and decomposition of organic matter proceeds. When the reservoir destratifies, the nutrients that were restricted to the hypolimnion are redistributed in the water column. The release of nutrients to surface waters, where light is sufficient to stimulate photosynthesis, results in increased phytoplankton production. In unstratified reservoirs, there is continuous circulation of the water column. Nutrients and organic matter are readily recyclable and remain available in the productive areas for continuous assimilation.

Reduced Compounds

20. Anoxic conditions found in the hypolimnion of lakes and reservoirs result in the formation of reduced species of iron, manganese, sulfur, and nitrogen. These substances may become a nuisance to recreational and industrial water users, and may be detrimental to aquatic life when they are released. These reduced compounds are converted to less noxious, more assimilable compounds in the oxidizing environment of the epilimnion, and their effect does not generally persist for more than 24 hours. Objectionable iron, manganese, nitrogen, and sulfur compounds are seldom a problem in well-mixed, unstratified reservoirs.

PART III: RESERVOIR OUTLET STRUCTURES AND THEIR IMPACT ON THE TAILWATER ENVIRONMENT

21. Water quality conditions in reservoir tailwaters are determined by processes occurring in the reservoir (discussed in the preceding section) and the design and operation of the project outlet works. The following brief discussion is intended to provide general information concerning the design and operation of reservoir outlet structures. It should be emphasized that each project is unique in design and operation; therefore, many project features will not be specifically discussed in this section.

Design Considerations

22. Most Corps of Engineers (CE) impoundments fulfill multiple purposes including navigation, flood control, hydropower, recreation, water supply, etc. Emphasis has been placed on effectively designing and operating projects to meet all intended purposes. For approximately the past 15 years, CE reservoir projects have been designed considering the water quality of project releases.

23. Numerous design options are available to assure that project releases are compatible with tailwater habitat objectives. Most notable is the incorporation of a selective withdrawal structure which can release water from various strata within the reservoir to meet downstream objectives. For selective withdrawal to be a viable alternative, density stratification must occur within the reservoir. This stratification may be due to vertical temperature differences within the impoundment, and/or the occurrence of stratification due to the concentration of dissolved constituents. Those reservoirs that are vertically well mixed have little need for selective withdrawal. Typically, such reservoirs are shallow, may have a short hydraulic residence time, and are often dominated by surface wind mixing.

24. Stratified reservoirs provide an excellent opportunity for effective operation of selective withdrawal structures. Releases can

be made to meet downstream requirements of tailwater fisheries and also reduce the impact of flood control operations on the tailwater.

25. Most older flood control projects were designed primarily to release waters from the bottom of the reservoir. Often, these waters are low in dissolved oxygen, but because of aeration that occurs in the outlet works it is not uncommon for dissolved oxygen in release waters to approach 95 percent saturation. Releases from hydropower projects receive little aeration due to the requirements to keep turbulence at a minimum.

26. Release of minimum flows to meet downstream habitat objectives is an important consideration of project design and operation. Projects with large bottom sluice gates are generally unable to discharge low flows since the gates can not be operated with the necessary precision or they vibrate violently when attempting to pass low flows under high hydrostatic head. This problem can be overcome with the addition of low flow bypass gates that can regulate releases to less than 1 m^3/sec. Also, sluice gates can be designed to incorporate low flow piggyback gates to release minimum low flows.

Operation Considerations

27. Flood control operation of a project is designed to attenuate and delay peaks in the inflow hydrograph, thereby reducing potential damage caused by increased downstream water levels. The attenuation of peak flood flows is obtained by storing water and releasing it through time. Therefore, the reduction in peak flow results in longer periods of high flow downstream. In many instances, reservoir discharges are reduced as high flows enter upstream to permit the downstream tributaries to discharge before reservoir flood waters are released.

28. Flood releases from reservoirs are often hypolimnetic because the bottom sluice gates generally have the largest capacity. Thus, if epilimnetic withdrawals were occurring prior to the storm event, the downstream area may experience cold hypolimnetic release waters during the passage of the flood waters before returning to epilimnetic release

schedules. If the project has a selective withdrawal structure, a portion of the releases can be made from near surface waters to reduce changes in downstream temperatures.

29. Hydropower is generated by two types of projects. Run-of-the-river projects generally provide baseload generation. The production rate of power is determined primarily by the amount of water flowing into the reservoir. Their relatively small capacity precludes their use in hydropower peaking operations. The hydraulic residence time of the water in run-of-the-river projects is usually quite short, and therefore, the water quality of reservoir releases is often quite similar to that of the reservoir inflow. Hydropower projects associated with large reservoirs are ideal peaking power plants because of their short response time. Thus, as demand peaks, the turbines can generate electricity almost immediately. In general, hydropower project releases reflect the demand for electricity, discharging only minimum low flows during the weekend and at night. These projects are brought on line depending on the demand for power.

Summary

30. Efforts to manage a reservoir tailwater to reflect conditions in an unregulated stream or river are impractical and often impossible because of constraints imposed by the design and operation of the project. Thus, the quantity, quality, and timing of releases creates an environment which differs from a natural stream. Understanding the impacts of project releases on the tailwater environment, as well as efforts to minimize detrimental effects and possibly improve downstream conditions, are often determined by overall project design and operation.

PART IV: PHYSICAL AND CHEMICAL DESCRIPTION OF TAILWATERS

31. Impoundments cause three major physical modifications in natural stream conditions: (a) seasonal temperature changes are delayed and the amplitude of diurnal and seasonal temperature fluctuations may be reduced, (b) high natural streamflows are reduced or eliminated and replaced by more moderate discharges over an extended period of time; and (c) sediment transport is reduced (Neel 1963; Maddock 1976). In addition, discharges may degrade the streambed and banks, resulting in "armoring" of the streambed. Impoundments also affect the chemical characteristics of the discharge including concentrations of dissolved oxygen, organic matter, nutrients, and reduced compounds.

32. The magnitude of these physical and chemical modifications is dependent on conditions within the reservoir (e.g., enrichment as related to age, duration, and degree of thermal stratification; hydraulic residence time; density currents) and the depth and volume of discharge (Neel 1963). The water quality of reservoir releases can be further modified by conditions in the tailwater such as groundwater inflow, runoff, streamside vegetation, and atmospheric influences.

Physical Characteristics

Temperature

33. Water temperatures in the tailwater are determined primarily by climatic conditions and the depth of release. Some tailwaters are subject to sudden, drastic temperature changes, whereas in others the changes are more subtle. Temperature alterations frequently result in the elimination of organisms from habitats where they might otherwise survive. Many aquatic organisms present in a stream have distinct temperature requirements, and changes of 1°C can affect their existence (Britt 1962).

34. Epilimnetic release dams on warmwater streams provide the tailwater with well-oxygenated water near or at atmospheric

temperatures. Warmwater fish species found in these tailwaters are well adapted to release water temperatures. Pfitzer (1954) noted little difference in the warmwater fisheries in tailwaters below Tennessee Valley Authority dams built on warmwater streams when water releases were from the epilimnion. However, epilimnetic releases from reservoirs built on coldwater streams can increase summer water temperatures in the tailwater and stress coldwater species. The temperatures of epilimnetic discharges from Ennis Reservoir, Montana, were 4°C higher than those in the coldwater stream above the reservoir. This temperature increase caused growth retardation in trout more than 270 mm long, but did not affect smaller fish and invertebrates (Fraley 1978).

35. Water temperatures are lowered below hypolimnetic release reservoirs built on historically warmwater streams. Faunal changes are generally more pronounced in rivers below these reservoirs than in rivers below epilimnetic release or nonstratifying impoundments. Several investigators have noted reductions in warmwater species caused by coldwater discharges below hypolimnetic release reservoirs built on warmwater streams (Dendy and Stroud 1949; Edwards 1978).

36. Coldwater discharges from deep-release dams on warmwater streams may result in tailwater temperatures as much as 20°C lower than the temperatures of unregulated streams of the region during the summer (Ward and Stanford 1979). A 10°C reduction in water temperature below Norris Reservoir, Tennessee, changed the tailwater from a warmwater to a coldwater stream (Tarzwell 1938). Average water temperatures 11.3 km below Tenkiller Dam, Oklahoma, during June and July were reduced by 4.3°C after impoundment (Finnell 1953). Reductions in water temperature have permitted the establishment of put-and-take trout fisheries in some tailwaters that were previously too warm to support trout.

37. During fall, hypolimnetic discharges from stratified reservoirs may provide warmer than normal water to the tailwater, effectively delaying the autumn decline in temperatures. River ice formations may be delayed during winter by lags in temperature change, and some tailwaters may be kept completely ice-free by the release of 4°C bottom water (Neel 1963). Delays of 20-50 days in the spring rise in

water temperature have also resulted from release of hypolimnetic water (Crisp 1977).

38. Seasonal temperature changes are also delayed in tailwaters below nonstratified reservoirs. Normal temperature changes are retarded because the time required to cool or warm the reservoir is significantly longer than the time required to cool or warm an unregulated stream. Additionally, diurnal and seasonal temperature fluctuations take place in unregulated streams, whereas temperatures in tailwater areas are more nearly constant, especially near the reservoir outflow. Marked reductions (up to 80 percent) in diurnal temperature fluctuation have been recorded (Fraley 1978). Before closure of Flaming Gorge Dam, seasonal temperatures on the Green River, Utah, ranged from 2°C in March to 22°C in July. After impoundment, water temperature fluctuations were reduced and ranged between 2 and 10°C (Vanicek and Kramer 1969).

39. Severe water temperature fluctuations may occur below dams during periods of low flow or no flow, because of atmospheric influence. Such periods are particularly characteristic of hydropower projects where changes in water discharge depend on power demand. Temperature fluctuations of 6-8°C may occur 2 to 3 times a day below these dams (Pfitzer 1968). If 2 or 3 consecutive days of no flow occurs, water temperatures can approach mean air temperatures. The sudden release of large volumes of cold hypolimnetic water during the summer may cause thermal shock. Fish kills have occurred when cold, hypolimnetic waters, with reduced levels of dissolved oxygen, were suddenly released into a tailwater after several days of little or no flow (Krenkel et al. 1979).

40. Thermal changes caused by hypolimnetic discharge can persist in a tailwater for an extended distance downstream. The effects of an altered temperature regime below a hypolimnetic release reservoir in Canada were noted by the depletion of the benthic fauna 100 km downstream (Lehmkuhl 1979). Air temperature, discharge volume, groundwater and tributary additions, shade, and substrate type all play a role in modifying the tailwater temperature as the water moves downstream. At some point downstream, where the influence of the reservoir lessens,

the interaction of these factors results in the return of the stream to preimpoundment conditions.

Flow

41. Natural streams are subject to large fluctuations in flow as a result of variations in precipitation. Seasonally, flows are highest in the spring and lowest in the late summer or early autumn, although intermittent floods may occur as a result of periodic storms.

42. Impoundments can drastically alter the flow characteristics in stream systems. Tailwater flows may be relatively uniform or may fluctuate frequently, depending on the method of dam operation and downstream water requirements.

43. Flood control and irrigation dams generally reduce the mangitude of flood flows, and release these flows at reduced volumes over longer periods of time. The reduction or elimination of floods reduces bank erosion and bed scour and decreases the amount of sediment washed into the tailwater from the flooded bottom lands. The resultant bank and bed stability enhances the growth of aquatic and terrestrial vegetation (Neel 1963). The encroachment of streamside vegetation, which is important in temperature regulation, shading, and in providing food for invertebrates, can further increase bank and floodplain stability. However, such increased vegetative encroachment may result in the eventual loss of part of the water-carrying capacity of the stream channel through a reduction in channel size (Bovee 1975; Maddock 1976).

44. Uniform flows below flood control and irrigation dams often benefit the invertebrate community through the establishment of dense mats of periphytic algae. These algal mats constitute both a habitat and a food supply for benthic organisms incapable of living in a more barren stream. However, these mats may eliminate species adapted to clean rock surfaces (Ward 1976c).

45. Flow fluctuations are more frequent and of greater magnitude below hydropower dams than in natural streams. Large daily flow fluctuations often preclude the establishment of permanent streamside vegetation. The alternate inundation and exposure of the streambed, coupled with extreme variations in flow, may remove much of the aquatic

biota from the tailwater (Neel 1963). A sudden increase in flow may remove algae, macrophytes, and sedimentary detritus, in addition to benthic invertebrates. Sudden decreases in flow may strand attached or immobile species and result in their desiccation (Lowe 1979). Overall, the diversity and abundance of tailwater habitat and fish and invertebrate food supply may be significantly reduced by radically fluctuating flows (Neel 1963). Recent studies (Matter et al. 1981) demonstrate that the surge of water from a peaking hydropower plant, and resultant bed scour may indirectly benefit tailwater fish by making benthic foods more available.

Substrate

46. Because reservoirs act as sediment traps, there is usually little sediment in reservoir discharge. This loss of sediment in the discharge, coupled with the removal of fine particles by the current below the dam, results in a tailwater streambed composed primarily of coarse cobble and bedrock. Ultimately an equilibrium is reached between the particle size of the remaining substrate and the stream's capacity to transport material. Upon reaching this equilibrium, further degradation of the tailwater streambed by scouring is halted (Komura and Simmons 1967). Increased flow rates below some hydropower facilities reduce bank and streambed stability, thereby causing increased bank erosion, streambed scour, and eventually armoring. Smaller sediment particles are swept downstream and deposited in pools and slackwater areas.

Turbidity

47. Turbidity can reduce or eliminate aquatic life in a stream. Decreased light penetration in turbid streams inhibits the establishment and maintenance of autotrophic plants, which may in turn effectively limit higher life forms (Ruttner 1963). Additionally, sedimentation resulting from turbid conditions eliminates invertebrate habitats by filling the interstices of gravel substrates. Sedimentation may also cover fish spawning sites and interfere with oxygen transport to buried fish eggs (Fry 1960).

48. Tailwaters are usually clearer (less turbid) than the reservoir inflow, particularly below deep-release reservoirs. Turbidity below reservoirs is significantly affected by sedimentation within the reservoir, density currents, discharge depth from the dam, and the inflow from surface runoff and tributary additions. Turbidity was reduced up to sixtyfold in the tailwater below Yellowtail Dam, Montana, by the settling of suspended matter within the reservoir (Soltero et al. 1973). Density currents carrying fine suspended matter, however, may sometimes flow beneath or through the main body of water in stratified reservoirs and be discharged directly into the tailwaters with little alteration within the reservoir (Churchill 1958). In these instances, mineral concentrations and turbidity may increase significantly in the tailwater. Turbid conditions may also result from the flushing of loose materials into tailwaters from unstable riverbeds and streambanks during periods of high discharge, and from tributary inflow.

Chemical Characteristics

49. Chemical properties that may affect the tailwater biota are the concentration of dissolved gases (i.e., oxygen, nitrogen), pH, particulate organic matter, available nutrients, and reduced compounds. Because of the variability of factors involved in altering water quality, few general statements can be made that are applicable to all tailwaters. Chemical properties of the water immediately below a dam depend on water quality within the reservoir at the level of release. As the water moves downstream, local conditions influence water quality and tend to characterize each individual tailwater (Pfitzer 1954).

Dissolved gases

50. Dissolved oxygen. The concentration of dissolved oxygen in an aquatic system is dependent on water temperature, biological oxygen demand, atmospheric exchange, and primary production. Water temperature determines the solubility of oxygen, and thus the amount of available oxygen in streams. This is an important factor in regulating the metabolic rates of cold-blooded animals, since their rates of

metabolism increase with temperature. The solubility of oxygen decreases as water temperature increases. At 100 percent saturation, 14.16 mg/l of dissolved oxygen may be in solution at 0°C but only 7.53 mg/l at 30°C (Boyd 1979). Decomposition rates of organic matter increase with increasing temperature, resulting in an additional depletion of oxygen content. The rate of decomposition generally increases between 5 and 38°C. Temperature increases of 10°C often double the rates of decomposition and oxygen consumption (Boyd 1979).

51. Most streams are relatively well oxygenated due to turbulent flows and continual atmospheric exchange. In quiet pool areas with dense algal vegetation, diurnal variations in the concentration of dissolved oxygen are directly linked to the amount of photosynthesis and respiration taking place in the system (Hoskin 1959). Oxygen concentrations are highest during the day and lowest at night.

52. The concentration of oxygen in tailwaters depends on the type of reservoir, depth of water release, water mixing during release from the dam, and downstream flow conditions. Low dissolved oxygen concentrations normally do not occur below surface-release reservoirs. Water from the epilimnion is usually well oxygenated as a result of photosynthesis and atmospheric gas exchange.

53. In deep-release reservoirs, biological decomposition of organic matter in the hypolimnion during the summer may result in the discharge of poorly oxygenated water into the tailwater. The low oxygen content of these waters may not satisfy the biological and chemical demand, especially if there are additions of domestic and industrial pollution downstream from the dam (Fish 1959).

54. Tailwater oxygen levels may also be reduced by the oxidation of iron and manganese present in hypolimnetic releases. This reduction may cause physiological stress to the aquatic community and further reduce the assimilation of organic wastes by stream organisms. Low-oxygen conditions may also intensify the potentially toxic effects of other chemical constituents--including ammonia and hydrogen sulfide, which are often present in the anoxic hypolimnetic water.

55. Reaeration of deoxygenated water can be rapid, and serious oxygen depletions can be avoided if tailwater conditions are such that biological and chemical oxygen demands are not excessive. Wirth et al. (1970) documented a consistent concentration of 7 mg/l dissolved oxygen in discharges from a deep-release reservoir in which the hypolimnion was devoid of oxygen. Reaeration during discharge is credited with maintaining the high dissolved oxygen level.

56. The rate of reaeration below deep-release reservoirs depends on the turbulence of the flow in the tailwater, atmospheric influence, and extent of photosynthesis by aquatic vegetation below the dam. Low oxygen levels may persist farther downstream during peak flow periods, when riffle areas are inundated and more laminar flow conditions exist. Below an Oklahoma hydropower project, dissolved oxygen concentrations were low (1.5 mg/l) for 3.2 km downstream during periods of moderate discharge, but extended 8 km downstream (2.0 mg/l) at peak flows (Summers 1954).

57. Oxygen concentrations greater than 5 mg/l are generally preferred by most stream fish (Fry 1960). They appear to survive well in streams where dissolved oxygen content occasionally falls below 5 mg/l at night but rises above this level during the day. Certain current-oriented aquatic invertebrates can withstand dissolved oxygen concentrations less than 1 mg/l if current velocities remain high (Bovee 1978).

58. When dissolved oxygen deficiencies occur in tailwaters, they adversely affect the health of fish through suffocation, growth retardation, and decreased disease resistance. Macroinvertebrates may also be adversely affected, but tolerant organisms usually replace those that have abandoned the areas because of low oxygen levels. Oxygen reductions that are not great enough to retard fish growth generally do not impair fish food resources (Doudoroff and Shumway 1967).

59. Gas supersaturation. Gas supersaturation can occur in tailwaters when water is spilled over high dams, trapping air and plunging it to the stream below where hydrostatic pressure is sufficient to increase solubility of atmospheric gases (Weitkamp and Katz 1980). The

high levels of dissolved gases produce embolisms in a variety of fishes and invertebrates. The supersaturated gases come out of solution within the fish's or invertebrate's body and form bubbles under the skin; severe cases can cause death. The condition is most common in tailwaters below hydropower reservoirs in the Pacific Northwest and has been attributed to both spillway and turbine releases (Feiningen and Ebel 1970; Ruggles and Watt 1975). Crunkilton et al. (1980) reported on the occurrence of gas supersaturation in a warmwater tailwater in Missouri. Spillway deflectors are reported to effectively reduce the level of gas supersaturation in water passing over a spillway (Weitkamp and Katz 1980).

Hydrogen ion concentration and alkalinity

60. The distribution of organisms in an aquatic system is determined to a large extent by the hydrogen ion concentration (pH) of the water. Changes in the pH of surface waters are often brought about by addition or removal of CO_2 during photosynthetic activity, decomposition of organic matter, and gas exchange. Fluctuations in pH, unless extreme, are not harmful in themselves, but variations may intensify or decrease the effect of toxic substances within the water column (Fry 1960). Waters with a pH from 6.5 to 8.6 are most productive, and fish populations are unaffected by slight deviations within this range (Fry 1960). Additions of acid mine drainage or industrial wastes may result in extreme deviations from these acceptable limits and stress some aquatic organisms (Edwards 1978). Aquatic insects have been shown to have little tolerance for pH below 4 (Canton and Ward 1977). Effects on fish become lethal when the pH falls below 4 or rises above 11 (Swingle 1961).

61. Diurnal fluctuations in pH of unpolluted surface waters are reduced through buffering by an alkalinity system of carbonates and bicarbonates, and the degree of buffering effectiveness depends on the concentration of these substances in the watershed. Total alkalinity may range from less than 5 mg/ℓ as $CaCO_3$ (little buffering capacity present) to several hundred milligrams per litre (Boyd 1979).

Productivity in natural waters is related to their total alkalinity (Turner 1960; Hayes and Anthony 1964). Waters within an alkalinity range of 20 to 400 mg/l are generally considered biologically more productive than those with higher or lower alkalinities (Moyle 1945).

62. There are no apparent trends in pH and alkalinity values in tailwaters, other than seasonal changes brought about by thermal stratification (Vanicek 1967; Pearson and Franklin 1968). Bacterial decomposition of organic matter in the hypolimnion increases the concentration of carbon dioxide, thereby reducing the pH in the tailwater. Turbulence in tailwaters increases gas exchange, which reduces the concentration of carbon dioxide; consequently pH rises as the water flows downstream. Alkalinity values in tailwaters below hypolimnetic release reservoirs are reduced during spring runoff but increase during the summer, when the reservoirs become thermally stratified (Vanicek 1967; Charles and McLemore 1973; Hannan and Young 1974).

Particulate organic matter

63. Particulate organic matter (POM), the organic component of the seston (Cole 1975), is the main food supply for detritivores in natural stream ecosystems. Concentrations of POM present in a stream are often positively correlated with flow rates, which are, in turn, determined by the amount of rainfall in the watershed (Webster et al. 1979). Concentrations of POM are highest during leaf fall in autumn and this source is gradually depleted from the stream during the rest of the year.

64. The POM may be separated into course and fine fractions. The coarser materials tend to move only a short distance downstream before they are trapped by obstructions and reduced in size by mechanical and biological processes. The finer particles are generally carried farther downstream until a reduction in the flow velocity allows the particles to settle out.

65. Deep-release reservoirs reduce the transport of most suspended POM to the stream below. Settling and decomposition in the reservoir may remove 70 to 90 percent of the particulate organic matter introduced from the watershed (Lind 1971; Armitage 1977). Most

allochthonous organic matter is washed into the reservoir during high winter or spring flows and is subsequently decomposed and transformed into dissolved nutrients during the period of summer stratification (Webster et al. 1979). The loss or reduction of this food supply for bacteria, fungi, and certain macroinvertebrates can reduce the abundance of these organisms in the tailwaters. Density currents with high levels of POM may flow through reservoirs--underneath, through, or above the main body of water--and be discharged into the tailwater, and when this occurs concentration of POM in the tailwater increases.

66. In contrast, surface-release reservoirs tend to increase the concentration of POM in the tailwater through the discharge of large populations of sestonic plankton produced in the epilimnion of the reservoir. The amount of plankton received from the reservoir fluctuates seasonally; it is greatest during peak production periods (turnover) in spring and fall. Microseston in the effluent of Lake Laurel, California, was 85 percent more abundant than that in the inflowing stream (Maciolek and Tunzi 1968). Filter feeding invertebrates may flourish below these epilimnetic release reservoirs due to the increased availability of food particles.

67. Concentrations of POM in tailwaters below reservoirs with short hydraulic residence times may not differ substantially from those in reservoir inflows. Short hydraulic residence time does not allow sufficient time for production of enough phytoplankton or settlement and decomposition of enough suspended organic matter to significantly alter the POM concentration received by the tailwater.

Nutrients

68. Minerals and nutrients characteristic of the surrounding watershed are carried into streams by surface runoff and tributary inflow. The amount of nutrients made available to a reservoir depends on the nature of the soil, amount of rainfall, local agricultural practices, and domestic and industrial sewage inputs. Significant short-term increases in minerals and nutrients during periods of intense runoff are characteristic of unaltered streams; whereas waters released from reservoirs are more uniform in mineral and nutrient

content (Wirth et al. 1970). Nutrient enrichment of a tailwater is a function of the enrichment of the reservoir above, reservoir stratification, depth of release, and hydraulic residence time.

69. Stratified reservoirs that have surface outflows trap nutrients in the deep hypolimnetic waters (Wright 1968). Total dissolved solids, nitrogen, and phosphorus concentrations decrease in the epilimnion during the summer through the assimilation of these nutrients by seasonally increased phytoplankton populations. In addition, adsorption to clay particles and subsequent settling may reduce phosphorous concentrations in the epilimnion. Moribund plankton from the epilimnion and organic material carried by the inflowing water continually settle out, enriching the hypolimnion as decomposition and nutrient transformation takes place.

70. The retention of nutrient rich hypolimnetic water may increase the potential productivity of the reservoir (Murphy 1962); however, continual inflows of dissolved and suspended nutrients may result in a noticeable deterioration in water quality (Johnson and Berst 1965). The biological productivity of the tailwater below a stratified surface-release reservoir is reduced during the summer because of the decrease of dissolved nutrients in the discharge. In the fall, however, after the reservoir becomes vertically mixed and nutrients are uniformly distributed in the water column, the availability of nutrients in the tailwater is increased and productivity improved.

71. Deep-release reservoirs discharge the nutrients which accumulate in the hypolimnion during stratification. The reduced oxygen concentration, resulting from decomposition, enhances the accumulation of dissolved nutrients (Hannan and Young 1974). As a result, more nutrients are discharged from the hypolimnion in the form of readily usable ammonia and dissolved phosphate. The release of clear, nutrient-rich water, more fertile than that released from the surface, often results in increased productivity in the tailwater. Objectionable taste, odor, and excessive algal production are often associated with these releases. Dense algal mats, sometimes established below these

reservoirs as a result of the increased nutrients, are usually associated with increased numbers of invertebrates, providing a food base for tailwater fish. Increased algal growth and the subsequent increases in macroinvertebrates can aid in the establishment of a trout fishery (Pfitzer 1954).

Reduced compounds in tailwaters

72. Hypolimnetic discharges may contain high concentrations of reduced iron, manganese, sulfur, and ammonia produced by naturally occurring anaerobic processes. High concentrations of these materials may be toxic to tailwater biota, or affect certain life stages at sublethal levels (Lehmkuhl 1979). Dissolution of these substances from the soil and decomposed organic matter occurs in the reservoir when the hypolimnion becomes anaerobic and the redox potential is lowered. A combination of these elements may have a synergistic effect, so that no one element or compound is solely responsible for toxicity to the biota (J. M. Grizzle, Auburn University, unpublished manuscript). The release of anoxic hypolimnetic water may produce combinations of toxic elements that normally would not be present in unaltered streams or in epilimnetic release tailwaters.

73. Iron and manganese. Soluble reduced forms of iron and manganese begin to oxidize upon release from the reservoir and precipitate in the form of ferric and manganic hydroxides that may stain concrete and rock surfaces in the tailwaters. These poorly soluble hydrous metal oxides are a nuisance to downstream municipal water treatment plants. Deposits of these hydroxides on the substrate below hypolimnetic release reservoirs may also affect the numbers and types of organisms present. However, the effects of these deposits have not been sufficiently documented (Krenkel et al. 1979).

74. Iron concentrations in neutral or alkaline waters usually range from 0.05 to 0.20 mg/l (Stumm and Lee 1960). The highest acceptable concentrations of iron are 0.30 mg/l in domestic water supplies and 1.00 mg/l for freshwater aquatic life (U. S. Environmental Protection Agency 1976).

75. The chemical characteristics of manganese are similar to those of iron; however, manganese has a slower oxidation rate and forms more soluble salts than iron. Manganese concentrations are not as effectively eliminated from the water column by precipitation (Wetzel 1975). Soluble forms of manganese are therefore more persistent in tailwaters. Below stratified deep-release reservoirs, manganese concentrations may exceed 1 mg/l, which is greater than concentrations found in most freshwater environments (Churchill 1958; Martin and Stroud 1973). Concentrations less than 50 μg/l have been found to inhibit green and blue-green algae in streams and to favor diatoms (Wetzel 1975).

76. Hydrogen sulfide. Occurrence of hydrogen sulfide in hypolimnetic discharges is the result of the anaerobic bacterial decomposition of organic sulfur compounds and the reduction of sulfates to sulfides within the reservoir. Hydrogen sulfide concentrations are highest and most toxic under acidic conditions (low pH). In neutral or alkaline waters, the sulfides combine with iron, forming insoluble ferrous sulfide, which precipitates from the water. Thus, hydrogen sulfide appears only when pH is low and oxygen content is near zero, or when all available iron has been precipitated from neutral or alkaline water (Symons et al. 1964).

77. Discharges with hydrogen sulfide concentrations above 0.002 mg/l have an objectionable odor and may result in fish kills and in a reduction in diversity of benthos and algae. Smith et al. (1976) reported a 72-hour LC_{50} of 0.019 mg/l for bluegill eggs at 21.9°C and a 96-hour LC_{50} 0.04[illegible] mg/l for adult bluegills at 19.6-20.3°C. Fish die-offs and adverse benthic responses have been attributed to high levels of hydrogen sulfide (Wright 1968).

78. Ammonia. Ammonia nitrogen (NH_3-N) is a by-product of organic decomposition (Cole 1975). In some situations, depending on the pH of the water, NH_3 may be toxic to living organisms. Concentration of NH_3 increases as pH increases, and NH_3 is most toxic when both dissolved oxygen and carbon dioxide levels are low (Boyd 1979). Toxicity is also affected by temperature and alkalinity (Lloyd and Herbert 1960).

Concentrations between 0.6 and 2.0 mg/l are lethal to fish after short-term exposure (European Inland Fishery Commission 1973, in Boyd 1979). Pathological changes in fish organs and tissues have been noted after continuous exposure to sublethal concentrations between 0.006 and 0.34 mg/l (Smith and Piper 1975, in Boyd 1979).

79. In late summer or early fall, the concentration of NH_3 increases in the anoxic hypolimnion of stratified reservoirs as the result of extensive anaerobic decomposition of organic matter. Additional NH_3 may be released from the bottom sediments or may be carried into the hypolimnion by density currents (Hannan 1979). Consequently, ammonia concentrations in tailwaters below hypolimnetic release dams tend to increase during late summer or early fall. Ammonia concentrations also increase in tailwaters below epilimnetic release dams during fall, after the fall overturn.

PART V: METABOLISM AND TROPHIC STRUCTURE

80. The assemblage of organisms living in a particular reach of a tailwater may be considered a biotic community. In this community, the interactions between the various types of organisms (i.e., primary producers; primary, secondary, and tertiary consumers, etc.) are based primarily on their nutritional requirements and feeding habits. The complex nutritional and energy cycle that results from this interaction is often referred to as the trophic system, within which each type of organism occupies a particular level.

81. Energy enters the tailwater trophic system in the form of light energy and nutrients and detritus. These materials are used by the primary producers and consumers that make up the lower trophic levels of the system. Energy is progressively transferred upward through the system when the organisms in these lower trophic levels are eaten by the secondary and tertiary consumers that make up the higher trophic levels.

82. As the energy is transferred from one level to another, losses result from the partial use of the available energy required for maintenance and reproduction. Generally, each successive trophic level contains only about 10 percent of the energy available to the preceding one (Russell-Hunter 1970). The net result is that only a small percentage of the original energy is available at the highest trophic level. Greater biomass production at the primary level, enabled by increased input (e.g., primary production, detritus), usually results in greater biomass production at the highest trophic level (Bovee 1975).

Streams

83. In streams, metabolic essentials are not recycled and must be constantly supplied from upstream sources or streamside vegetation. Metabolic activity and productivity are additionally governed by the composition and sources of the nutrients entering the stream and how efficiently they are utilized.

84. Stream organisms take up, transform, use and release organic materials, thus acting as processors of the organic material passing through the system (Fisher 1977). Fish, the largest organisms in the stream community, usually represent the top level of the food chain. Their abundance reflects the quantity of primary and secondary production that takes place in lower levels of the trophic system.

85. The organic content of a natural stream system comes from allochthonous and autochthonous sources. The metabolism for both sources is based on the supply of detritus which is used as food by detritivores and omnivores and furnishes dissolved nutrients to the primary producers. An allochthonous system (heterotrophy) is based primarily on organic material that is carried into the system from the watershed. Autochthonous systems (autotrophy) derive their energy from photosynthesis that takes place in the streambed. These systems are most representative of slower flows, which enable a buildup of periphytic vegetation and, occasionally, vascular plants.

86. In contrast to the source of organic materials in most ecosystems, that in streams is derived primarily from allochthonous sources (Hynes 1970; Cummins 1974). A headwater stream, for example, may derive 99 percent of its energy inflow from allochthonous origins and the remaining 1 percent from photosynthesis (Fisher and Likens 1973; Cummins 1974). Higher order streams may also depend on allochthonous sources of energy.

87. As much as 60 percent of the total organic matter taken into the stream from allochthonous sources may be in the form of leaf litter (Cummins 1974). Additional allochthonous materials may be in the form of twigs and shoreline debris or dissolved nutrients from watershed runoff. Leaf material may be found in suspension in the stream or deposited on the streambed (Minshall 1967). The leaves are rapidly colonized by fungi and bacteria, which aid in processing the material into fine particles and dissolved organic matter. The dissolved nutrients released during decomposition are then available for use by primary producers. The colonizing fungi and bacteria are in turn used as food by the shredding and scraping invertebrates that are involved

in the mechanical aspects of leaf decomposition. The fungi and bacteria may be the primary source of nourishment for these invertebrates, since some leaves have been shown to be of little food value. These invertebrates, in turn, make up the primary prey of predators in the higher levels of the trophic system (Cummins 1974).

88. The structure and complexity of the benthic community may change with the amount and variety of plant detritus present in the system (Egglishaw 1969; Mackay and Kalff 1969). As the organic material breaks down, the variety of food becomes more diversified, producing a similar response in the invertebrate community. Seasonal shifts in the diversity of the stream invertebrates are related to changes in food supply and other natural changes during the life cycle of the organisms (Mackay and Kalff 1969).

89. Since many aquatic invertebrates are able to process organic matter at low temperatures, much of the organic material in streams is used during fall and winter. However, not all of the organic matter entering the system during fall is used. Some of the material is stored in the slower depositional zones of the stream, where it remains until used by the stream biota. These zones act as energy reservoirs and help maintain the biota annually. Material in depositional zones may be redistributed during flooding. This redistribution may be important in slow-water zones, in reducing the occurrence of oxygen deficiencies that could develop during extended periods of reduced flow.

90. Autotrophic production varies as a result of differing environmental situations (e.g., changes in shading, turbidity, water velocity, and water chemistry). Autotrophic production is greatest in streams with little shading from streamside vegetation, and in small streams in forested areas before and after formation of a leaf canopy (spring and fall). Photosynthetic activity is greatly reduced in heavily shaded streams, even when adequate amounts of nutrients are available.

91. Autotrophy may be the major contributor to the energy budget of large rivers or small uncanopied streams (Minshall 1978). Removal

of a canopy results in a shift from a heterotrophic to an autotrophic system, as stream temperature and photosynthetic production both increase (Gelroth and Marzolf 1978). Photosynthetic activity by periphytic algae takes place primarily in shallow, well-oxygenated, and well-lit stream bottoms. The periphyton is usually the first autotrophic component to become established in a stream, and is most prevalent where flows are least variable. Phytoplankton become dominant in rivers and large streams where depth and turbidity inhibit benthic production by the attached algae (Fisher and Carpenter 1976).

92. Faster current velocity in riffle areas, as opposed to pools, results in increased rates of net primary productivity (Kevern and Ball 1965). Steep diffusion gradients between plants and available nutrients are formed in the fast-flowing water, allowing for more rapid assimilation of vital substances by the attached algae or macrophytes. Because of these steep diffusion gradients, many algal species grow best in swift currents (>15 cm/sec) (Whiteford 1960). Phosphorus uptake may be over 10 times greater and respiration over 70 percent greater in swift water (18 cm/sec) than in still water (Whitford and Schumacher 1961).

93. Dense, feltlike, dark green or brownish communities, consisting mostly of diatoms, may be established in streams with swift currents (McIntire 1966). Diatoms such as Gomphonema, Diatoma, or Navicula, which require high light intensities and solid substrates, are commonly found in swift streams in association with filamentous algae such as Cladophora. The accumulation of attached algae on gravel and rubble is more rapid in fast currents, but the growth stabilizes after a time and the total biomass per unit area is similar to that in slower currents. However, higher productivity is maintained in the faster current, allowing a greater export of biomass (McIntire 1966).

94. Slow currents (<15 cm/sec) may allow associations of green filamentous algae (including Stigeoclonium, Oedogonium, and Tribonema) to develop (McIntire 1966). These associations appear as bright green aggregations similar to those found in ponds. Concentrations of organic matter are usually higher in streams dominated by green algae than in those dominated by diatoms. Conversion from a diatom-moss

association to a community of *filamentous green algae* (possibly associated with rooted aquatic macrophytes or diatoms) may indicate a shift to a more autotrophic stream system (Cummins 1974).

95. Macrophytic vegetation develops in streams where flows are relatively stable. This vegetation is seldom consumed and therefore does not directly contribute to higher trophic levels while alive (Cummins et al. 1973; Fisher and Carpenter 1976), although they may serve as a surface for periphyton. However, when the vegetation dies and decomposes, it contributes organic matter to the system. Streams subject to severe changes in flows physically limit the development of significant plant growth. Additionally, these plants are not found where insolation to the stream is low or where the water is relatively deep and turbid.

Tailwaters

96. A variety of types of organic matter, leaves, POM, algae, etc., must be present in the stream to maintain ecosystem diversity (Cummins 1972). However, reservoirs act as particle traps, interfering with the passage of detritus into the tailwater. As a result, detrital material from the watershed, important in energy transformation in natural streams, is largely unavailable to a tailwater system.

97. Nutrient material present in the clear discharges of hypolimnetic release reservoirs is primarily in a dissolved state as a result of decomposition by-products that accumulate in the hypolimnion (Odum 1971). Water discharged from the hypolimnion may be more fertile than that from the epilimnion because of the concentration of these dissolved nutrients in the deep water.

98. Tailwaters immediately below hypolimnetic release dams are autotrophic because concentrations of dissolved nutrients are increased and turbidity is decreased. The clear, nutrient-rich discharges are particularly important in tailwaters with stabilized flows because they facilitate the production of dense algal growths (Stober 1963; Ward 1976b). However, as the water moves farther downstream, conditions

(i.e., increased turbidity, reduced nutrient availability) become less conducive to algal production. The gradual increase in the detritus load due to allochthonous input results in a reversion of the tailwater to a heterotrophic condition in which the algal community plays only a relatively limited role. It may, therefore, be possible for a section of stream below a reservoir to shift from an autotrophic system in the immediate tailwater area to a heterotrophic system downstream, with an area of transition in between.

99. Two genera of filamentous green algae, Cladophora and Ulothrix, are commonly found below deep-release reservoirs (Stober 1963; Ward 1976b). Mats of Cladophora were located in riffles in the first 9.6 km below Tiber Reservoir, Montana (Stober 1963). The formation of these algal mats may physically inhibit the production of the most desirable fish food organisms but may attract other taxa (Welch 1961; Ward 1976b). The algal mats may act as barriers to organisms that require deeper substrates for completion of their life cycles (Armitage 1976).

100. Water discharged from surface-release reservoirs, whether stratified or not, may contain significant amounts of plant debris and detritus, but the primary source of organic matter in the tailwater is plankton produced in the reservoir. Plankton can be used directly by secondary consumers in the tailwater or, after death and decomposition, may add to the particulate organic matter that is available to both primary and secondary consumers. Thus, most surface discharges from reservoirs supply particulate organic matter to tailwaters, and deep discharges supply dissolved organic matter.

101. Phytoplankton may occur in zones of the tailwater where the water velocity is reduced and the streambed widened, and adequate nutrients are available. However, phytoplankton numbers decrease as the water flows farther downstream because of depletion of nutrients, increased turbidity, and simple mechanical destruction (Hartman and Himes 1961).

102. Storage of inflowing water for extended periods (e.g., as in flood control reservoirs), accompanied by reduced downstream releases,

may result in bank stabilization and the eventual establishment of streamside vegetation in tailwater reaches. Streamside vegetation in these areas increases both the amount of shade and the quantity of allochthonous materials in the tailwater. The establishment of macrophytic vegetation and periphytic algal growths are also enhanced when stabilized flows are accompanied by reduced turbidities (Ward 1976b).

103. Management schemes for some reservoirs require that discharges be released at irregular intervals. For example, releases from flood control reservoirs may be erratic, since they usually depend on duration and amount of rainfall in the watershed. These flow irregularities result in a brief buildup of detrital material in the streambed of the tailwater during minimum releases. The subsequent release of runoff waters from the reservoir may scour the tailwater, resulting in a physical disruption and alteration of the stream similar to that in a natural stream after a heavy rainfall (Trotzky 1971). The periodic releases may sweep the streambed free of accumulations of leaf litter and detritus deposited by adjacent streamside vegetation (Ward 1976b). The tailwater is thus denied an important source of energy (Radford and Hartland-Rowe 1971).

104. In tailwaters subject to daily variations in water release (e.g., peak power hydropower facilities), detritus and sediment are constantly flushed away (Ward 1976a). Enrichment with particulate organic matter is marginal at best, particularly near the dam, and the lack of detritus places further stress on the trophic structure of these waters. Fluctuations in water level increase streambed and bank erosion thereby increasing turbidity and discouraging the establishment of streambank vegetation and streambed algal growth. These conditions may critically limit the tailwater biota, which might otherwise thrive.

105. Tailwaters are highly modified environments that may be subject to extreme conditions not normally found in natural streams. Because of these modifications, the tailwater biota may be disrupted or enhanced. Either development will result in the creation of a trophic structure much different from that normally found in an unaltered stream.

PART VI: AQUATIC INVERTEBRATES IN TAILWATERS

Invertebrate Ecology

Streams

106. Benthic stream communities are extremely dynamic and are composed of a large number of species (Patrick 1970). Many have intricate life cycles adapted for survival in the changing environment found in most streams (Brusven et al. 1976). Their life cycles are characterized by short generation times, high reproductive potentials, and reduced body sizes (Patrick 1970). The adults of most important stream insects are terrestrial, short-lived, and concerned only with breeding and dispersal (Hynes 1970).

107. The bottom fauna is not randomly scattered and its distribution results from interaction of the invertebrate's habitat requirements with the varying environmental conditions that exist in different areas of the stream (Allen 1959). The mosaic pattern of distribution exhibited by benthic organisms is primarily determined by current velocity, substrate type, and food availability (Ward 1976a; Minshall and Minshall 1977). In addition, temporal and spatial temperature differences affect the presence of both individual species and life stages. Temporary colonization of microhabitats produced by changes in these variables increases the taxonomic diversity of the stream benthos and ensures a year-round food supply for fish (Ward 1976b). Outside interferences (e.g., pollution, impoundment) in a stream system tend to reduce the benthic diversity as a result of the reduced diversification of available microhabitats (Ward 1976a).

108. Flow. Current velocity may have the most influence on the regulation of invertebrate distribution and abundance, especially at specific sites in the stream (Chutter 1969; Giger 1973). However, the influence of current velocity on invertebrate densities in different sections of the stream may be masked by the effects of other variables (Chutter 1969). Some stream organisms have morphological respiratory and feeding demands that require them to position themselves in flowing

water (Ward 1976a). As long as the stream velocity remains relatively high, and the supply of food and oxygen is adequate, these organisms can survive (Bovee 1975). However, life stages adapted to fast water die when subjected to slow current and reduced oxygen because they are physiologically unable to adjust to the altered conditions. Relatively high stream velocities are required to ventilate the delicate gills of these organisms and they must be exposed to the current (Giger 1973; Armitage 1976). In addition, filter-feeding insects are deprived of food if the current fails to carry materials into their food-gathering nets.

109. Many stream organisms move about in a "boundary layer" or dead-water zone (up to 1 mm in thickness) near the interface of the substrate and water where current velocities are substantially reduced (Ambühl 1959; Ward 1976a). The boundary layers and dead-water zones formed in and around substrate components provide many types of habitat and locations for invertebrates. Rough substrates result in an increase in thickness of these boundary layers and a tendency toward more rapid reduction in the current velocity (Bovee 1975).

110. Strong stream currents discourage free-swimming invertebrates. Insects living in the swift-water areas are morphologically modified to withstand the mechanical forces of the current. Most adaptations enable insects to avoid many of the adverse effects of strong currents by keeping their bodies away from the force of the flow (Hynes 1970). Fusiform, flattened, and streamlined bodies aid survival in swift currents by enabling insects to "crouch" in the boundary layer. Because morphological modifications force them to face upstream, most voluntary movement is upstream (Hynes 1970). Temporary attachment structures are common adaptations that enable insects to release and reattach themselves after a period of uncontrolled movement in the current. Some organisms construct cases of small stones, detritus, or silk that are anchored firmly to the substrate. These organisms catch organic particles from the water by either using morphological filtering mechanisms or constructing nets.

111. Reduced current velocities limit the abundance and diversity of swift-water invertebrate communities, either physically because of

siltation or physiologically because of inadequate oxygen and nutrient exchange (Giger 1973). An extreme reduction in current eliminates species that are dependent on flow for respiration and food procurement (Sprules 1947).

112. Freshets, flow cessation, riffle sedimentation, water level fluctuations, and unstable substrates result in changes in the species composition and may catastrophically reduce the stream fauna (Sprules 1947; Peterson 1977). Severe floods and spates scour and flush insects from the streambed, leaving only the species able to withstand the increased flows (Hynes 1970). Scouring may reduce the numbers of insects in a particular section of a stream by 50 percent (Sprules 1947).

113. Spates that scour the stream substrate result in temporary dislocation and dispersal of invertebrates, but the density and structure of the community may recover to preflood conditions within 30 days if the insects are not dispersed over great distances. After seven floods in Big Buffalo Creek, Missouri, the structure of the invertebrate riffle community was very similar to that found in the same location before the floods (Ryck 1976). Apparently, enough organisms are left after spates or other disturbances to repopulate the stream section. They escape the effects of the disturbances by maintaining themselves in the protected areas of the stream where flow is reduced (Patrick 1970).

114. Most stream organisms are protected from the effects of severe flooding and relatively short periods of dewatering because they are imbedded in the upper 15 to 22 cm of the gravel substrate (Hynes 1974). The movement of trichopterans into deeper strata of the stream bottom may be indicative of their response to scouring or to increased sediment loads that accompany flood waters (Poole and Stewart 1976). In addition, extended hatching periods and firmly attached eggs also ensure that certain species are not eliminated during stream disturbances (Hynes 1970). The repopulation of a riffle sections is probably a result of a combination of several factors, including downstream drift, upstream larval movement, and upstream egg-laying flights of adults (Ryck 1976).

115. Substrate type. In most streams, pools and riffles form the most distinctive types of habitat. Formation of pools and riffles is a combined process of dispersion and sorting of the bottom materials. Pools are associated with stream bends, and riffles with crossings and inflections in the streambed. Fine particles are washed away from riffles and deposited in pools, leaving only the larger gravels and rubble in the riffle area (Yang 1971). Riffles provide optimal environmental conditions for many species and are diverse, productive invertebrate habitats. Invertebrates produced in riffles may potentially be swept into the pools, where they are likely to be eaten by fish (Peterson 1977). More insects are usually produced in riffles than in pools or on bedrock or submerged vegetation because current velocities are higher in riffles and rubble substrates increase the availability and number of microhabitats. Insects inhabiting the pool areas are similar to those found in ponds and lakes and feed on the accumulation of organic matter that forms sediment (Krumholz and Neff 1970; Cummins 197[illegible]).

116. Intermediate zones, which may occur between stream riffles and pools, are called "runs" (Luedtke et al. 1976). These are areas of moderate flow over relatively shallow stretches of the stream and may be depositional or erosional, depending on the current velocity. The identity and abundance of benthic fauna present are determined by whether the area is in a depositional or erosional zone.

117. The benthic fauna associated with specific substrate types generally forms a well-defined community. Any change in the substrate results in an accompanying change in invertebrate species (Sprules 1947; DeMarch 1976). Large rubble (45-70 mm in diameter) has a variety of microhabitats, which may be inhabited by all sizes of insects. This type of substrate is found in swiftly flowing areas of streams where smaller sized substrate materials are washed away. The organisms found here are adapted to living in habitats that offer reduced contact with the current (Cummins 1966). Invertebrates able to survive in small-particle (5-2[illegible] mm) substrates are, by necessity, small and

resilient (Sprules 1947). Their microhabitats are commonly destroyed or altered during high, irregular flows.

118. Manipulations of streamflow may alter the detrital "trap" capacity of the substrate and ultimately affect species composition and stream productivity. Small detrital particles and silt tend to accumulate excessively in the interstices of small-particle substrates, whereas in rubble habitats the interstices are swept clean by the current. As a result, many aquatic insects prefer substrates composed of moderately sized (25-45 mm) particles because they serve as a better benthic food trap without reducing habitat diversity (Rabeni and Minshall 1977).

119. Some species of insects are able to take advantage of increased sedimentation, but usually suspended and settled sediments adversely affect the invertebrate population. At low flows and reduced current velocities, silt and sand seal the interstices in a rubble substrate. This sealing restricts access to the undersurfaces of the stones and generally reduces the number of usable habitats. The sediment is easily displaced into suspension at higher flows and settles out in depositional zones where flows are reduced. The problems caused by sediments are sometimes lessened by the development of carpets of algae over the streambed, which may replace microhabitats filled in with sediment (Brusven and Prather 1974).

120. Macroinvertebrates apparently migrate out of areas exposed to heavy sediment loads. Their response to sedimentation is rapid, and only a few days are required for numbers to decrease significantly. Conversely, their response to a decrease in sedimentation results in a rapid recovery of the community. Sandy substrates are generally unsuitable for insect production because of the instability of the sand particles and the thinness of the protective "boundary layer." Upstream movement of riffle insects in sandy areas is generally precluded by the effects of current on the fine, loosely compacted sediments. Low current velocities and rubble substrate facilitate upstream movement of invertebrates (Leudtke and Brusven 1976).

121. Food. A mature stream ecosystem is highly diverse, and includes complex food webs (Krumholz and Neff 1970). The increased complexity of links in the food web increases the chances of survival of the stream community. A fluctuating autochthonous food supply supplemented by allochthonous nutrients increases survival because species are not restricted to a single food item (Russell-Hunter 1970).

122. Although benthic crustaceans, mollusks, and other small invertebrate life might be present, aquatic life stages of insects are the most abundant forms of primary consumers in most streams. Their diets vary greatly (e.g., the forms represented may include herbivores, detritivores, carnivores, and omnivores) and some forms shift from one source to another seasonally (Chapman and Demory 1963). A change from herbivory in the early instars to carnivory in the later instars is common (Anderson and Cummins 1979).

123. Food gathering and the associated morphological and behavioral adaptations are the most important functions of animal consumers in a lotic system (Cummins 1972). Food habits are more closely related to the size of the organism than to the species. Most early life stages and small-sized insects feed primarily on detrital components (Cummins 1972). Aquatic insects are opportunistic and are able to adjust to differing availabilities of food; very few are strictly herbivores or strictly carnivores. Minshall (1967) noted the presence in a small benthic community of 14 percent herbivores, 3 percent carnivores, and 83 percent omnivores. Food availability is generally not a limiting factor for mobile stream organisms because they are able to actively seek food (Krumholz and Neff 1970).

124. Macrophytic communities often shelter larger and more varied populations of invertebrates when they are composed of plants with finely divided leaves, rather than plants with simple leaves. Herbivores harvest periphyton from the surface of the leaves and use the maze of vegetation for shelter and protection (Harrod 1964).

125. The riffles may provide a number of diverse foods for invertebrates, ranging from plant detritus lodged under stones to clumps of algae and moss associated with the stream bottom. The accompanying

invertebrate communities may differ greatly among the various types of food sources (Egglishaw 1969).

126. The food base of invertebrates living in slow-water areas or pools primarily depends on the deposition of detrital material washed in from upstream. Water in pools may be too turbid and the current too slow to allow the establishment of sufficient benthic algal growths, and too deep to allow the development of significant quantities of macrophytes.

127. The aquatic insect component of the stream benthos has been classified into four feeding types: shredders, scrapers, collectors, and predators (Cummins 1973). The life cycles of shredder-type aquatic insects are closely associated with leaf fall in autumn. Most of their growth and development occurs during late fall and winter. These organisms are able to adjust their growth rates to the relative availability and quality of food. Observations on shredders have indicated a positive selection of leaf material that is heavily colonized by microorganisms, both on the surface and throughout the matrix of the leaf particle (Anderson and Cummins 1979).

128. Scrapers are dependent on the production of an autochthonous food source from which they literally "scrape away" required food particles. The nutritional content of this potential food source (mostly algae) is much higher than that of a detrital food source (Coffman et al. 1971). These organisms are most often in the mainstream channel, where the dominant foods are diatoms and filamentous green algae (Cummins 1972).

129. Collectors filter fine particulate organic material containing surface colonies of bacteria and fungi from the stream flow. The assimilation of nutrients by filter feeders is inefficient and much of the material is passed downstream, unmodified, where it may be reingested by other organisms. This process results in a type of unidirectional "spiralling" cycle in which many organisms, each feeding on different components, are able to utilize filterable organic material. Without this filter-feeding community, much of the suspended organic material would pass through the system unused (Wallace et al. 1977).

130. Predatory insects have high assimilation efficiences, largely because the nutritional quality of their prey is very high. However, the quantity of prey may vary and is usually limiting (Anderson and Cummins 1979).

131. Feeding habits partly determine the location and limit the presence of invertebrate types in a stream. Filter feeders live in moving water with a seston load, scrapers in areas where algal growth is most apt to become established, shredders in areas of leaf litter and detrital accumulation, and predators in any or all of the available feeding locations, depending on the abundance of the potential prey population.

132. Temperature. Diurnal temperature fluctuations are generally required for normal growth and development of stream insects, whereas static temperatures are usually disadvantageous (Ward 1976c). Life histories of most stream organisms are geared to annual temperature cycles which synchronize the particular life stages and stimulate growth (Hynes 1970; Gore 1977). Triggering mechanisms for excystment, encystment, and other vital developmental processes may not be stimulated when temperatures remain unchanged; differences of a few degrees affect developmental times and durations. Higher temperatures are accompanied by reduced concentrations of dissolved oxygen and increased metabolic demands, and cool temperatures produce a metabolic slowdown (Bovee 1975). The absence of a certain species from a stream section may result from one of the specific temperature requirements not being met. For example, Epeorus sp., a heptageniid ephemeropteran, has been shown to require near-freezing temperatures for a certain length of time for the development of diapausing eggs. Additionally, newly hatched nymphs require an extended period (2.5-4 months) of relatively high temperatures (18-28°C) for normal development and maturity (Britt 1962).

133. Numbers and biomass of invertebrates in the streambed may fluctuate radically because of differing rates of development and emergence (Patrick 1962). Invertebrates emerge in the same sequence each year, but the dates of first emergence and the duration of the

hatch vary, depending on water temperatures (Sprules 1947). Insects may emerge to mate and deposit eggs all year, but the greatest emergence takes place during the evening hours in spring and early summer (Chapman 1966). During emergence, the population of a particular species in the stream may be reduced to near zero (Hooper 1973; Brusven et al. 1976). Alterations in stream temperature during this time may cause an extended period of oviposition, resulting in several ages and sizes of nymphs (Minshall 1968). Competition among the progeny of a species, as well as between various insect species with similar life requirements, may be partly averted by the staggered deposition of eggs and subsequent differences in developmental rates (Minshall 1968). The early stages of many aquatic invertebrates are small and essentially unavailable as fish food (Chapman 1966).

134. Densities of insects may vary seasonally, depending on species composition. In northern temperate streams, the benthos generally reaches a numerical maximum in the fall and early winter after eggs hatch (Cummins 1973). Periods of maximum stream invertebrate biomass may not occur concurrently with the numerical maxima. The greatest invertebrate biomass generally occurs in the spring and fall during peaks of growth. The abundance of organisms with short life cycles varies considerably with environmental conditions (Patrick 1962). If they reach maturity by fall, additional eggs are deposited which undergo development during the winter months (Cummins 1973). Some species, however, require a full year of development to reach maturity.

135. Environmental stress. Benthic stream macroinvertebrates have traditionally been good indicators of past and present environmental stress because of their long life cycles and relatively sedentary behavior. Changes in community structure are sensitive indicators of environmental alterations (Cairns and Dickson 1971). The most sensitive species are eliminated from the stream, resulting in diminished competition among the surviving organisms. Only those species able to tolerate a wide range of environmental conditions are able to survive when life requirements become limiting (Bradt 1977).

136. Short-term exposure of the stream community to intolerable conditions may result in alteration of the diversity and density of the fauna. More tolerant species increase in number, because of the lack of competition, until they reach their limits of space and food (Cairns and Dickson 1971). Additional alteration of an already stressed environment will eliminate one or more of the remaining species, resulting in a major reduction in the standing crop.

Tailwaters

137. Invertebrate living conditions in a tailwater are different from those in a natural stream and are dependent primarily on the characteristics of the reservoir discharge. To survive, benthic organisms must be able to adapt to the changes in primary production and the altered physical-chemical characteristics of the tailwater system (Krumholz and Neff 1970; Jonasson 1975).

138. The effects of reservoir releases on the downstream biota depend on the type of dam and the subsequent flow patterns, release depths, and resiliency of the natural stream benthos. Macroinvertebrate species composition and diversity may either be substantially enhanced or reduced, depending on the characteristics of the flow in the tailwater (Ward 1976a). The benthos below reservoirs generally respond to the unnatural conditions with reduced taxa and increased numbers of certain species (Spence and Hynes 1971a). Tailwater insects are smaller and are considered to be of marginal food value for fish (Powell 1958; Bauer 1976). The number of species increases progressively downstream in response to the greater availability and variety of microhabitats and the presence of increased quantities of detritus from streamside vegetation and runoff (Hooper 1973; McGary and Harp 1973). However, total numbers of individuals may be highest near the dam, since systems with few species often are more productive and support a greater biomass than those with many species.

139. Factors which inhibit benthic populations in tailwaters include alterations in natural yearly temperature changes, isothermal temperatures, siltation (in some flood-control sites), daily water-level fluctuations, streambed scouring, reduced concentration of particulate

organic matter, altered water quality, and seasonally altered flows (Vanicek 1967; Hoffman and Kilambi 1970; Isom 1971; Ward 1976b). Conversely, stabilized flows, decreased turbidities, the introduction of seston from the reservoir, increased nutrient availability, and the growth of algae and moss increase benthic standing crops. The magnitude of the inhibiting and beneficial effects depends on the schedule of water release, the withdrawal depth, and the length of time water has been retained in the reservoir.

140. Fluctuating flows. High releases following periods of little or no flow result in scouring and turbidity, and fluctuating water levels cause increased bed and bank instability (Ward 1976a). Reduced flows result in decreases in wetted perimeter, depth, surface area, and current velocity. Water temperatures during these periods become increasingly subject to ambient atmospheric influences (Pfitzer 1962; Ward 1976a). The extreme changes in flow often create conditions that are unsuitable for most stream benthos. Because of this, invertebrates are least abundant in immediate tailwater areas that are subject to extreme periodic flow fluctuations. Insect densities in the tailwater may be as much as 30 times less than those of streams flowing into the reservoir (Powell 1958; Trotzky 1971). However, downstream moderation of the effects of flow fluctuation often results in the gradual increase of invertebrate densities (Radford and Hartland-Rowe 1971; Trotzky and Gregory 1974; Ward 1976b).

141. Continually fluctuating flows interfere with the establishment of a stable benthic community because of the preference of various species for a narrower range of environmental conditions (Pearson et al. 1968). Daily water level fluctuations generally reduce the production and standing crop of stream invertebrates by eliminating both the benthic food base and the benthos (Bovee 1975; Ward 1976a). This situation is particularly obvious below hydropower projects where maximum discharges occur during periods of peak power demand and minimum discharges when power demands are lessened. In these instances, two entirely different stream habitats are created. The tailwater may change from a typical pool-riffle association during minimum releases

to a deep, swift stream during maximum releases. Most affected is the "zone of fluctuation," which is composed of side channels, backwater areas, and shallows. These areas alternately undergo the physical disruption of microhabitats during high flows and dewatering and substrate exposure during reduced flows. Insects in these areas become dislodged and physically destroyed during high flows, and they are also subject to stranding and desiccation during reduced flows (Powell 1958; Trotzky 1971). In tailwaters with fluctuating flows, the lack of permanent, clearly defined pools and riffles precludes the survival of most stream insects.

142. Some benthic tailwater communities subject to regular, periodic water-level fluctuations may eventually attain a resonable level of production (Odum 1969). In these "mature" tailwaters, a few species (probably two or three) that have adapted to the flow changes make up the vast majority of the benthic community (Pfitzer 1962). Members of these benthic communities apparently tolerate brief periods of substrate exposure if it is not severe (Fisher and LaVoy 1972; Ward 1976a). No significant difference was found between numbers of insects living on nonexposed substrates and those living on occasionally exposed substrates (13 percent exposure time) in a "zone of fluctuation" below a hydropower dam on the Connecticut River, Massachusetts (Fisher and LaVoy 1972).

143. Vegetative mats act as a refuge for insects in some tailwaters during brief periods of exposure because of the retention of moisture in the vegetation. Insects living near the "mat-rock" interface are more likely to survive than those found on the surface of the vegetation (Brusven et al. 1974).

144. Low air temperatures also increase the chances of survival for organisms stranded in a tailwater and enable them to tolerate dewatering for longer periods than during high air temperatures. Brusven et al. (1974) reported that larvae of chironomids, lepidopterans, and trichopterans could survive dewatering for 48 hours in cool weather, but that high air temperatures and longer exposure periods resulted in high mortalities.

145. In spite of the ability of some insects to survive periodic exposure, most insect species that inhabit tailwaters are found in the permanently submerged habitats not subject to daily exposure (Powell 1958; Brusven and Trihey 1978).

146. The lack of flow fluctuation in tailwaters below flood control reservoirs can disrupt the benthic community. In fact, stable releases for 3 to 4 weeks followed by moderate or extreme discharges may cause more stress and mortality to an insect community than the frequent pulsed releases found below hydropower dams (Brusven and Trihey 1978). The stable periods encourage the colonization of the tailwater substrate, but benthic organisms which are not able to adjust to subsequent severe flow increases are catastrophically swept downstream.

147. The high seasonal discharges below flood control reservoirs may also destroy the pool-riffle areas nearest the dam and replace them with an extended "run" section. Farther downstream, however, pools and deep channels may be present which act as buffers to fluctuating water levels and as refuges for invertebrates during periods of minimal releases (Powell 1958).

148. Chironomids are the most resilient group of insects found in unstable areas and are the first to recolonize denuded zones of fluctuation (MacPhee and Brusven 1976). They may be found in association with oligochaetes, amphipods, and isopods in coldwater tailwaters subject to rapid water-level fluctuations (Brown et al. 1968). These invertebrate associations are able to adapt to temporary periods of exposure by either migrating out of the exposed area or surviving in the thin layer of water which remains after the stream recedes.

149. Insects most affected by fluctuations in flow are the groups which are generally regarded as quality fish food, including mayflies, stoneflies, and caddisflies (Powell 1958; MacPhee and Brusven 1976). Nymphs and larvae of these species are most subject to desiccation, since their eggs can usually survive extended periods of exposure. The number of insects affected by desiccation, therefore, depends on when a flow reduction occurs and the life stages of the insects present. Desiccation of the streambed would affect the population drastically

during a larval hatch, but unhatched eggs may remain relatively unaffected (Hynes 1958).

150. Stabilized flows. Reservoirs with stable releases have relatively stable tailwater substrates (Ward 1976a). The associated invertebrate fauna stabilizes as flows and substrates become more consistent, resulting in reduced niche overlap and a shift toward community equilibrium (Blanz et al. 1970; Ward 1976c). Streamflow stability combined with reduced turbidity may enhance algal and macrophytic growth and provide additional food niches and microhabitat diversification for chironomids, oligochaetes, and mollusks (Armitage 1976; Ward 1976a). The stable environment and predictable resources tend to eliminate some species, resulting in a less diverse faunal assemblage with higher standing crops of the species present (Ward 1976b).

151. In tailwaters subjected to stable seasonal discharges, sedimentation may become limiting to the benthic community. Extended periods of minimal releases accompanied by moderate detrital and silt input from runoff and streamside vegetation effectively reduce the available microhabitats. The lack of spates, necessary to flush the detrital material from the substrate interstices, may eventually result in the complete elimination of these productive invertebrate microhabitats (Giger 1973).

152. Deep-release reservoirs. Cold water temperatures and poor water quality (low dissolved oxygen, reduced compounds) often occur in tailwaters below deep-release dams. Stratified deep-release reservoirs typically produce benthic tailwater communities which are low in diversity, but which may have high standing crops. This situation is typical of a stressed environment (Ward 1974, 1976c; Young et al. 1976; Pearson et al. 1968).

153. Modification of the normal temperature regime can affect the diversity and quantity of the benthic fauna several kilometres downstream from a coldwater release dam (Pearson et al. 1968; Lehmkuhl 1972, 1979; Ward 1976c). The overall change in temperatures, coupled with the delay of seasonal fluctuations, often results in the elimination of many invertebrate species from the tailwaters. Minimum winter

and maximum summer temperatures that would normally provide the thermal stimulus essential for the initiation of various life history stages of many stream invertebrates are never reached. Reduced growth efficiencies at the lowered temperatures may eliminate species which are unable to adapt metabolically to abnormally cold summer temperatures (Hannan and Young 1974). Alternatively, warm winter temperatures may accelerate growth rates and result in premature emergence and exposure to air temperatures that may be lethal or that may complicate the mating process (Ward 1976c). These conditions, along with delays in spring warming and autumn cooling, may prevent the natural hatching and growth of insects that have stringent thermal requirements (Lehmkuhl 1972).

154. The lack of daily fluctuations in water temperature may prevent the initiation of egg or larval development (Ward 1976c). Diel temperature fluctuations in a 24-hour period were as great as 10°C in an unregulated stream in England, but rarely exceeded 1°C in a regulated section (Armitage 1977).

155. Stresses imposed on aquatic invertebrates below deep-release reservoirs may also be due to low dissolved oxygen, the presence of high concentrations of H_2S and other decomposition by-products, or the interaction of these factors (Coutant 1962; Hicks 1964; Young et al. 1976). Reaeration of the water as it passes through a dam may increase the concentration of dissolved oxygen to a level tolerable by the tailwater biota, but the by-products (e.g., iron, manganese, hydrogen sulfide) of hypolimnetic decomposition may be more persistent and have a detrimental effect on tailwater organisms (Coutant 1962). If releases from the reservoir are increased, the harmful effects of the hypolimnetic discharges can be extended downstream.

156. Deep-release reservoirs do not necessarily release water of poor quality (low or no dissolved oxygen, reduced compounds) but assuredly produce a new environment which favors coldwater rather than warmwater organisms (Hoffman and Kilambi 1970). In stratified reservoirs where anoxic conditions and poor water quality do not develop in the hypolimnion, increased concentrations of dissolved nutrients, CO_2, and lowered turbidities may favorably affect the living conditions

of tailwater invertebrates (Penaz et al. 1968). In these circumstances, the benthic community may have characteristics similar to those of communities in streams with mild organic enrichment (Spence and Hynes 1971a).

157. Filterable food material (plankton, some benthic organisms, and miscellaneous seston) produced in deep-release reservoirs may be passed into the tailwaters during periods of complete vertical mixing. However, this is not a reliable food source since the plankton and seston are congregated in the upper strata of most reservoirs during stratification and are therefore unavailable to the discharge. As a result, filter-feeding invertebrates are often restricted to downstream tailwater locations, where discharge effects have been modified and sufficient amounts of filterable material have been introduced through runoff and tributary inflow (Ward 1976b). Plankton and benthos may be discharged from some deep-release reservoirs during stratification if the hypolimnion remains oxygenated.

158. Surface-release reservoirs. The downstream effects of a surface-release reservoir are usually similar to those produced by a natural surface-release lake (Ward and Stanford 1979). Water quality is generally not a problem and tailwater temperatures may only be moderately influenced in comparision to deep-release sites.

159. Shallow, surface-release reservoirs can produce abundant quantities of bottom fauna and plankton. Invertebrates in the tailwater may subsequently receive much of their food in the form of seston and insects from the reservoir discharge (Walburg et al. 1971). Because of the rich suspension of food in the reservoir release, filter-feeding insects, particularly trichopterans, may be extremely abundant in the tailwater. Generally, the increase in benthic density is accompanied by a reduced diversity and the elimination of some species. In formerly coldwater streams, the release of warm surface water from the reservoir during summer may result in a reduction or elimination of certain species from the tailwater (Fraley 1978; Ward and Short 1978).

Benthic Invertebrate Drift

Streams

160. Interspecific competition for food and microhabitats may result in an active downstream movement or "drift" by many benthic organisms (Waters 1969; Hildebrand 1974). The benthic invertebrate fauna and the drifting fauna are not distinct communities. Drift is merely a temporary event in the life cycle of most benthic organisms (Waters 1972).

161. Benthic organisms enter the drift when they leave their protective retreats and are swept downstream by the current. This process generally occurs at night during periods of feeding activity (Waters 1969). The feeding activity of each species is governed by a diel pattern based on photoperiod and is generally initiated at the same time each day (Elliott 1967; Waters 1972). The actual movement downstream probably occurs as a series of short hops with the turbulent flow assuring frequent contact with the substrate. The distance of passage depends primarily on velocity of flow and the species of invertebrate involved (Gore 1977).

162. When flows are suddenly increased, the physical disturbance of the streambed stimulates a catastrophic-like response from the benthos and their presence in the drift increases markedly (Elliott 1971; Brusven et al. 1976). The actual number of organisms in the drift per unit volume remains relatively stable during these periods, but the numbers passing a certain point in the stream over a period of time may increase significantly (Waters 1969). Natural spates in streams may disperse organisms over an increased living area or may displace them into stream environments such as pools and runs, where they find survival difficult and where they are more likely to be consumed (Waters 1969). Many benthic organisms die when they are swept downstream into physically or chemically unacceptable zones (Russell-Hunter 1970).

163. The drift may also be used as a means of escape from desiccation during low flows (Elliott 1971). Increases in the drift

result from a decline in available living space associated with drastic reductions in streamflow (Minshall and Winger 1968; Armitage 1977; Gore 1977). Areas downstream, relatively unaffected by reduced flows, may actually exhibit increased invertebrate populations as a result of the accumulation or organisms from dewatered riffle areas (Giger 1973).

164. Recovery of the bottom fauna after streambed exposure or other catastrophic events may be rapid (19-28 days) after natural conditions return (Herricks and Cairns 1974-76). Drifting organisms from upstream areas quickly recolonize the affected streambed. Recolonization of denuded areas may also be aided by a certain amount of upstream "crawling" movement, which may replace about 6 percent (by number) of the downstream loss due to drift (Bishop and Hynes 1969). The renewal of drift out of a disrupted area may be delayed until the community has recovered to a point where the benthic population exceeds the carrying capacity of the habitat (Dimond 1967). The failure of a formerly abundant species to repopulate an area after a stream disturbance may allow other species to become established, ultimately resulting in a shift in community composition and abundance (Waters 1964).

Tailwaters

165. Drift in tailwaters is primarily composed of organisms from the reservoir above, particularly below unstratified reservoirs and reservoirs with surface-release systems. Microcrustaceans and certain insect larvae (e.g., Chaoborus) produced in the reservoir commonly dominate the tailwater drift (Gibson and Galbraith 1975; Armitage 1977, 1978).

166. Drift of benthic organisms that live in the tailwater occurs primarily as a result of extreme fluctuations in reservoir discharge. Even species not normally found in the drift (e.g., Chironomidae) may enter the drift because of these fluctuations (Brooker and Hemsworth 1978). Increased drift may result in considerable reductions in the abundance of the stream fauna without actual streambed desiccation (Ward 1976a). Repopulation of denuded zones is obviously not possible from sources upstream, because of the presence of the reservoir. Recolonization is therefore dependent on several factors, including egg

deposition by adult insects which fly upstream, random oviposition of remaining individuals in the denuded zones, and upstream crawling or swimming by nonaerial invertebrates. Eggs deposited by insect species which are tolerant to the particular tailwater environment will develop. Other species, which are not adapted to the specialized conditions, will be eliminated.

167. Minimal daily fluctuations and seasonally stable flows may result in increased benthic populations (Ward 1976a). However, the stable flows that enhance benthic invertebrate development may reduce drift. Reduced drift in this instance may be detrimental to fish production by limiting the availability of prey (Chapman 1966).

168. Terrestrial insects may make a significant contribution to available fish food in the tailwater drift, especially in areas where streamside vegetation is abundant (Waters 1964). They may be attracted to the cool, moist areas of exposed streambeds below reservoirs during periods of reduced flows, and when discharges are suddenly increased, they are swept downstream with the drift (Pfitzer 1962). Since terrestrial insects are most active during daylight, they are more commonly found in the drift during the day than at night (McClain 1976).

Zooplankton

169. River and stream environments are poorly suited for the production and maintenance of zooplankton, and they characteristically harbor small zooplankton populations (Hynes 1970). Their abundance in flowing waters is inversely related to the rate of the current flow. Thus, the zooplankton present must be supplied to the stream from adjacent quiet-water areas or other suitable productive habitats in the drainage (Hynes 1970).

170. Most zooplankton found in tailwaters are produced in the upstream reservoir. Some zooplankton may be produced in backwaters and other quiet-water zones adjacent to the tailwater, but the input from these areas is not significant when compared with that of the reservoir. Therefore, the species and abundance of zooplankton found in the

tailwater are dependent on the species and abundance in the reservoir population (Brook and Woodward 1956).

171. The reservoir zooplankton community may vary as a result of seasonal population cycles. The community is also influenced to a large degree by the hydraulic residence time of the reservoir. Zooplankton numbers are generally higher in reservoirs with longer hydraulic residence times. Both of these factors eventually affect tailwater zooplankton abundance.

172. The amount of zooplankton passed into a tailwater depends on the depth of reservoir release. The zooplankton migrates vertically within the water column in response to changes in light intensity. This vertical migration may keep the zooplankton away from the level of discharge during certain periods of the day. Zooplankton abundance will also be altered in tailwaters below selective withdrawal dams, where changes in the level of withdrawal are made on a seasonal or daily basis.

173. Zooplankton transported into a tailwater from the reservoir provides a more readily available source of energy and protein than the detritus normally found in unregulated streams (Armitage 1978). Most of the zooplankton discharged from hypolimnetic-release reservoirs is already dead and simply contributes to the stream's load of organic debris. Moribund zooplankters settle out and decompose, providing a nutrient-rich detritus in the tailwater area (Armitage and Capper 1976). Seasonal inconsistencies in the reservoir discharge, however, preclude zooplankton from being a reliable source of either nutrient inputs or food for benthic consumption in the tailwater (Ward 1975).

174. Larger bodied zooplankters (e.g., copepods and daphnid cladocerans) may be common in tailwaters immediately below surface-release reservoirs, but they rapidly disappear as the water flows downstream. The progressive reduction in densities downstream is characteristic and has been documented by several investigators (Chandler 1937; Stober 1963; Ward 1975; Armitage and Capper 1976).

175. The zooplankton decrease which occurs between reservoir outlets and areas downstream is due to a combination of factors,

including the abundance of zooplankton discharged, the filtering effects of periphytic vegetation in the tailwater, physical destruction, predation, and adherence to or ingestion of silt and debris. Chandler (1937) indicated that zooplankton discharged from a reservoir in July was reduced 99 percent 8 km downstream; whereas, during February, when population levels were higher, abundance was reduced only 40 percent. Algae and mosses in the tailwater essentially act as filters, removing the zooplankton as it flows through the vegetation (Chandler 1937). Armitage and Capper (1976) noted that 99 percent of the zooplankton discharged had disappeared within the first few kilometres, the greatest losses occurring in the first 400 m below the dam. Larger organisms become entangled more easily and are eliminated from the streamflow sooner than smaller organisms. For this reason, greatest zooplankton reductions in tailwaters may occur when aquatic vegetation is abundant and the tailwater levels are lowest. When water levels in the tailwater are high and aquatic vegetation is absent, the vegetative filtering phenomenon is eliminated, and zooplankton may be more persistent downstream (Chandler 1937).

176. Zooplankton is also highly susceptible to physical abrasion and fragmentation. Some zooplankters are utilized as prey when flushed from the reservoir, benefiting populations of benthic macroinvertebrates and fish in the tailwater (Ward 1975). Other zooplankters either ingest or adhere to sand and silt in the turbulent tailwaters and become heavier, tending to sink and die.

Tailwater Effects on Specific Invertebrate Taxa

177. The productivity and occurrence of stream organisms in tailwaters are determined by physical-chemical stresses imposed upon the community. These stresses are related to the quantity and quality of the releases from the reservoir. Species normally present in a stream may be enhanced or reduced in a tailwater, but the structure of the tailwater community is generally much different from that of a natural stream.

178. Immature life stages of insects from four orders, including Diptera, Trichoptera, Ephemeroptera, and Plecoptera, are prevalent in natural streams. Other aquatic insects, mollusks, benthic crustaceans, oligochaetes, and planktonic invertebrates may also be abundant.

Diptera

179. In tailwaters, dipterans appear to be the group best adapted to the altered conditions of reservoir releases (Ward 1976c). Dense communities of Simuliidae and Chironomidae often occur in the immediate tailwater below deep-release reservoirs because major invertebrate predators are few and fish diversities are low (Ward 1976c). They may be the only invertebrates present because of their ability to adapt to conditions in most cold tailwaters. Farther downstream in the tailwater elevated water temperatures, predation, and microhabitat competition may result in reduced densities of both families and the possible disappearance of Simuliidae.

180. Simuliid larvae and pupae prefer cold water and are apparently tolerant of the poor water quality which occasionally occurs in tailwaters below deep-release dams (Hilsenhoff 1971; Goodno 1975). They are not common below surface-release dams or in tailwaters where water temperatures may become too high for their survival. The more diverse fauna which exists farther downstream from these dams additionally limits the establishment of simuliid populations because of increased invertebrate competition and predation.

181. The various species in the family Chironomidae are adapted to a wide range of environmental conditions, making them ideal tailwater inhabitants. Some prefer cold water, while others prefer warm water. Other species have more generalized requirements and may be found in a variety of conditions. The seasonally altered temperatures found in tailwaters below deep-release dams (winter warm, summer cool, and delayed maximum and minimum temperatures) may allow some species of chironomid larvae to survive during periods of the year when they would not be found in natural streams. However, these same alterations may modify emergence patterns, which are controlled by water temperature and light intensity (Oliver 1971). Adults in these

instances may undergo premature emergence resulting in disorientation and reduced survival.

Trichoptera

182. Most species of Trichoptera found in tailwaters are net spinners or filter feeders. Their abundance is directly related to the availability of seston discharged from the reservoir which, in turn, is dependent on the location of reservoir outflow (Rhame and Stewart 1976; Ward 1976a). Deep-release reservoirs provide an extremely unreliable food source because of the lack of seston during periods of stratification. Unstratified and surface-release reservoirs may, in contrast, provide a rich food source, including plankton and other suspended organic matter.

183. The success of a certain species may depend on the size of the food particles that are available. Individual species crop particles of specific sizes, depending on the mesh size of their gathering apparatus and their location in the streambed (Wallace et al. 1977).

184. Variations in flow also affect trichopteran survival. Adequate current velocities are necessary to supply food and oxygen to stationary larvae and influence the design and construction of food-gathering nets (Haddock 1977; Wallace et al. 1977). Sufficient flow is required to keep food-gathering nets extended, but higher flows will result in their destruction (Haddock 1977). Large flow variations below some dams may inhibit the survival and feeding success of some trichopterans, since food-gathering nets are swept away at high flows and collapse at low flows.

185. Larvae of some species of Trichoptera are found in quiet-water areas of natural streams. They are unable to withstand swift water and are not dependent on net-gathering mechanisms for their food supply. Quiet-water areas are uncommon below most reservoirs and if present they are subject to destructive periodic flow increases. As a result, most trichopterans found in tailwaters are adapted to living in swift water.

Ephemeroptera

186. Ephemeroptera (mayflies) typically inhabit small streams with large-rubble substrates. The number of species present depends primarily on the habitat diversity, since each species exhibits a high degree of habitat selectivity. Generally, the presence of more diverse habitats is reflected by an increase in the number of species (Macan 1957).

187. Ephemeropterans do not usually occur in tailwaters because the stable thermal regime found here does not provide the temperature stimulus required for life-stage development. They are additionally affected by the reduced habitat diversity and the absence of an adequate food supply (detritus). Downstream, where the effects of reservoir releases subside, mayflies gradually become more prevalent as the tailwater becomes more "stream-like" (Lehmkuhl 1972).

188. Ephemeropterans are rarely found in streams where velocities are below 15 cm/sec or above 91 cm/sec (Delisle and Eliason 1961). Few species are able to survive in areas subject to extreme flow reductions (MacPhee and Brusven 1973; Ward 1976a). Mayfly species equipped with hold-fast organs are able to exist in tailwaters with moderately high current velocities (Ward 1976a).

189. Most ephemeropterans do not readily colonize areas in a constant state of water-level fluctuation since they cannot tolerate both low and high flow extremes. One genus (Paraleptophlebia), however, has been found abundantly in tailwaters exhibiting these types of fluctuations (Trotzky and Gregory 1974).

Plecoptera

190. Plecopterans are usually not found in tailwaters because the loss of habitat heterogeneity, changes in flow regime, and relatively stable temperatures make conditions unacceptable for their growth and development. Downstream their abundance generally increases as the influence of the reservoir discharge declines (Ward 1976a). Several species of plecopterans (e.g., chloroperlids) are not affected by rapidly fluctuating flows, and may become abundant in tailwaters

where other environmental conditions are suitable (Ward and Stanford 1979).

191. Plecopterans are common predators on trichopteran eggs, chironomid larvae, and simuliid larvae in natural streams (Vaught and Stewart 1974). The absence of these predatory species contributes to the increased abundance of Simuliidae and Chironomidae in most cold tailwaters.

Miscellaneous

192. Amphipods, oligochaetes, isopods, mollusks, and turbellarians are often abundant in tailwaters. One factor common to these groups that may be significant to their abundance in tailwaters is the lack of an aerial adult stage in their life cycles. Because they do not have an aerial adult stage, they are not subject to the problem of premature emergence that often occurs among aquatic insects in thermally altered tailwaters (Ward and Stanford 1979).

193. Ward and Stanford (1979) indicated that amphipods are often abundant in tailwaters that have reduced summer temperatures and stable flow regimes. High nutrient inputs and reduced flood flows also favor amphipods because streambed siltation and increased macrophytic growth which occurs in these situations are highly beneficial to their development (Hilsenhoff 1971).

194. Oligochaetes may be present below deep-release reservoirs in pools away from the strongest currents. The cool, nutrient-rich water and lack of destructive spates favor establishment of dense populations in these areas (McGary and Harp 1973; Armitage 1976).

195. Isopods may be the dominant organism in the riffle areas of cold tailwaters (McGary and Harp 1973). They are also less affected by minor water-level fluctuations than other invertebrates because they can migrate out of areas that are periodically exposed.

196. The distribution of mollusks in natural streams is determined primarily by substrate patterns and types. The chemical and physical alterations that occur in tailwater environments have both enhanced and disrupted mollusk populations.

197. Enriched growths of attached algae and increased organic sediment were found to encourage the establishment of pulmonate snails (Physa) during the absence of scouring releases or during extended periods of reduced flows (Williams and Winget 1979). However, Harman (1972) found that chemical and biological alterations of the tailwater environment negatively affected the mollusk population and reduced species diversity. The number of mussel species was also reduced in the Tennessee River. Alterations to and loss of riverine habitat after extensive reservoir construction reduced the number of species from 100 to approximately 50 (Isom 1971). Formerly abundant species were reduced or eliminated and natural replacement was limited. The change in fish species that also occurred as a result of reservoir construction further reduced mollusk populations through the obstruction of fish-host associations that are a necessary part of the molluskan life cycle (Isom 1971).

198. Turbellarians appear to be a minor member of the tailwater invertebrate community and are not widely studied. Based on the few studies that have been conducted, turbellarians apparently increased in tailwaters with stable flow regimes and cool summer temperatures and declined in tailwaters with fluctuating flows (Ward and Stanford 1979).

199. Crayfish are common in some tailwaters; however, no mention of this group was made in the literature except as food for some fish species.

PART VII: FISHES IN TAILWATERS

200. In this section, fishes that commonly occur in tailwaters are discussed. The presentation is by family, followed by individual species or groups. Fish species which occur in tailwaters but are of only minor importance because few are generally captured or they are little mentioned in tailwater literature are not discussed. These include species from the following families: Petromyzontidae (lampreys); Acipenseridae (sturgeons); Lepisosteidae (gars); Anguillidae (eels); Hiodontidae (mooneyes); Aphredoderidae (pirate perches); Cyprinodontidae (killifishes); and Atherinidae (silversides).

201. A brief description of environmental conditions necessary for the successful completion of the various life history phases of each species or group is presented under the following topics: habitat, reproduction, food, and age and growth. This is followed by a synthesis of tailwater literature pertaining to a particular species or group of fish. Emphasis is placed on how the species responds to environmental conditions found in tailwaters. The depth of discussion varies by species and is dependent on the amount of literature available. Source material for the description of fish life history requirements was obtained from Carlander (1969, 1977), Scott and Crossman (1973), Pflieger (1975), and others.

202. The common and scientific names of fishes mentioned in this report are listed in Appendix C. Fishes from North American tailwaters are included in Part I and nomenclature follows that of Bailey et al. (1970). Fishes from European tailwaters are included in Part II. Life history information for the most common fish groups discussed in this report is given in Appendix D.

Polyodontidae (Paddlefishes)

203. The paddlefish is one of the largest freshwater fish in North America. It is found only in the Mississippi, Missouri, and Ohio Rivers and their larger tributaries. Numbers of paddlefish have

declined greatly since the advent of the twentieth century. Major causes are believed to be dams, overfishing, and pollution. Fish concentrate below dams where they are especially vulnerable to fishing. Dams built to create reservoirs or for other purposes have inundated many former spawning grounds or have prevented fish from reaching upstream spawning areas. The decline of paddlefish stocks in past years followed the increased release of domestic and industrial pollution into the waterways. Paddlefish populations have increased in some areas where pollution abatement has been effective (Eddy and Underhill 1974).

Paddlefish

204. Habitat. The paddlefish is primarily found in the open water of sluggish pools and backwaters of large rivers where it swims about continuously near the surface or in shallow water. For spawning, it requires access to a large, free-flowing river with gravel bars which are inundated during spring floods.

205. Originally the large free-flowing rivers of the Mississippi Valley provided ideal habitat for paddlefish. Now some of the largest populations are found in man-made impoundments where tributary rivers meet the fish's exacting spawning requirements. These conditions are met in some reservoirs in the states of Alabama, Arkansas, Kentucky, Missouri, Oklahoma, and Tennessee, and in several mainstream Missouri River reservoirs in North and South Dakota and Montana.

206. Reproduction. The reproductive habits of paddlefish were described by Purkett (1961), whose studies were conducted on the Osage River in Missouri. Spawning takes place in midstream, over submerged gravel-bars when the river is high and muddy in early spring at temperatures of about 15.5°C. Meyer and Stevenson (1962) reported that female paddlefish in Arkansas do not mature until they are over 11.34 kg in weight and that they may not spawn every year. The adhesive eggs stick to the first object they touch, normally stones on the streambottom. Eggs hatch in 9 to 12 days when water temperatures are about 16°C (Purkett 1963; Needham 1965). After hatching, the fry swim upward vigorously, then settle toward the bottom. Frequent repetition

of this activity by the fry is significant in that it permits the strong currents to sweep the fry downstream out of the shallows and into deep pools before the gravel bars are exposed by receding water levels.

207. Food. Paddlefish feed primarily on zooplankton and insect larvae filtered from the water. They swim slowly with their mouths open through areas where food is concentrated. Water passed through is filtered by the long, closely set gill rakers. The function of the paddle-shaped snout in relation to feeding is not known for certain, but its elaborate system or sense organs may enable it to function primarily as a device for locating concentrations of food organisms.

208. Age and growth. Paddlefish grow rapidly. According to Pflieger (1975), young nearly 150 mm long have been collected from overflow pools of the Missouri River in early July. Two specimens kept in a fertilized pond reached a length of about 0.9 m and a weight of 2.7 kg when they were 17 months old. Paddlefish in Lake of the Ozarks, Missouri, attain a length of 250 to 350 mm in their first year and about 530 mm in their second year. Seventeen-year-old fish average nearly 1.5 m in length and 16.8 kg in weight. The largest paddlefish are usually females. The species is also long-lived; many individuals live more than 20 years.

Paddlefish in tailwaters

209. Large concentrations of paddlefish are found in some tailwaters especially during winter and spring. Most studies on paddlefish in tailwaters are concerned with spawning and reproduction. Paddlefish reproduction, prevented primarily by the blockage of upstream migration by dams, has also been affected by the altered flow regimes found in tailwaters. Main-stem hydropower facilities on the Missouri River have not only reduced the amount of natural spawning area available but have also rendered most of the remaining river areas unusable. Large diel water fluctuations mask or delay the normal spring rise in water flows and temperatures.

210. Young-of-the-year fish have been reported in only one tailwater of the Missouri River reservoir system (Friberg 1974).

Juveniles found in Lewis and Clark Lake were produced in the 65-km section of the Missouri River above the reservoir, while those in the tailwater either passed through Gavins Point Dam or were produced in the 97-km section of natural river downstream from the dam (Walburg 1971; Friberg 1974). Recruitment from the reservoir above is believed to be the primary source for paddlefish found below Lake of the Ozark's hydropower dam on the Osage River in Missouri (Hanson 1977).

211. The effects of navigation or flood control dams on paddlefish reproduction are not as well defined. Successful spawning on eroded wing dikes below Lock and Dam Number 12 on the Mississippi River in Iowa has been regularly observed (Gengerke 1978). Eroded wing dikes effectively simulate natural gravel bars. The control of spring floodwaters below a Kentucky flood control reservoir appears to inhibit downstream spawning activity (Branson 1977).

212. An alteration of the behavioral characteristics of paddlefish caused by impoundments is evidenced by their concentration in the swift-flowing waters immediately below many dams (Friberg 1972; Boehmer 1973; Gengerke 1978). Concentration of these fish into a relatively confined area increases their vulnerability to both commercial and sport fishing. Friberg (1974) reported high catch rates of paddlefish in tailwaters for three to four years following dam closure, followed by declining catches due to reduced numbers. These concentrations during the reproductive season may be explained by the blockage of upstream migration. During other seasons these concentrations are most likely due to the increased availability of food in the reservoir discharge.

213. In tailwaters, zooplankton is most abundant in the reservoir discharge; its abundance decreases rapidly downstream. The large quantity of food available would tend to attract feeding paddlefish from slow-flowing areas into the faster flowing discharge, where they would normally not be found.

214. Except for the immediate discharge, there is generally less zooplankton available in the tailwater than in the reservoir. This relative scarcity of food is reflected in the reduced growth rates of tailwater paddlefish. Growth studies by Friberg (1974) indicated that

paddlefish apparently raised in a reservoir suffered a marked reduction in growth following passage through the dam into the tailwaters.

Clupeidae (Herrings)

215. The herring family is composed of species which are mainly marine or anadromous. Several species live in fresh water and are occasionally found in tailwaters. They are skipjack herring, gizzard shad, and threadfin shad. None are used for human food, but the skipjack is sometimes sought by sport fishermen because it fights spectacularly when hooked. Gizzard shad, particularly young of the year, are important forage for other fishes. Threadfin shad are important forage at all ages because their maximum length rarely exceeds 180 mm. The skipjack is not discussed further here because it is little mentioned in tailwater literature, except for an occasional occurrence in fish species lists.

Shad

216. Habitat. The gizzard shad in generally distributed over the eastern half of the United States where it is most abundant in reservoirs and large rivers. It inhabits quiet-water habitats in lakes, ponds, reservoirs, and backwaters of streams where fertility and productivity are high. Shad usually avoid high-gradient streams and those which lack large, permanent pools. Shad congregate into loose aggregations, and large numbers are often observed near the water surface. During fall, winter, and spring, large numbers may be found in tailwaters.

217. The threadfin shad, whose habitat is similar to that of the gizzard shad, is generally confined to the southeastern states where it has been stocked extensively in reservoirs for forage. It has also been stocked in reservoirs of the Southwest. It is sensitive to low temperatures, and extensive die-offs have been reported at temperatures below 7.2°C (Pflieger 1975). Because of overwinter die-off, annual stockings of adults are necessary to maintain populations in many reservoirs. Large numbers of this species may also occur in tailwaters during fall and winter.

218. Reproduction. Gizzard shad are very prolific and generally spawn during April, May, and June at temperatures between 17 and 23°C in shallow areas of protected bays and inlets. The scattered eggs sink to the bottom where they adhere to the first object they contact. Eggs hatch in about 4 days and the young begin feeding when 5 days old. Young attain typical adult form when about 32 mm long.

219. Threadfin shad begin spawning in the spring when the water temperature reaches 21.1°C and may continue throughout much of the summer. Threadfin spawn in schools near shore. The adhesive eggs stick to any submerged object and hatch in about 3 days. Young begin feeding when 3 days old. Individuals hatched early in the year commonly mature and spawn late in their first summer of life.

220. Food. The gizzard shad is almost entirely herbivorous, feeding heavily on microscopic plants, phytoplankton, and algae. The species is essentially a filter feeder, removing particulate matter from the water by passing it through its closely set gill rakers.

221. Threadfin shad are also filter feeders. Their diet consists of microscopic plants and animals found in the water column.

222. Age and growth. Gizzard shad average about 127 mm long at the end of their first summer, 185 mm at age I, 257 mm at age II, and 302 mm at age III (Carlander 1969). The average life span is 4 to 6 years but some live 10 or more years. Maturity is reached in the second or third year. Adults are commonly 230 to 360 mm long and weigh about 0.45 kg. Maximum length and weight is about 520 mm and 1.6 kg.

223. Adult threadfin shad are usually 102 to 127 mm long, and few live more than 2 or 3 years. In Bull Shoals Reservoir, Arkansas, threadfin shad average 53 mm in length at the end of the first growing season and 124 (males) and 135 (females) mm at the end of three growing seasons (Bryant and Houser 1969).

Shad in tailwaters

224. Shad are important forage species in tailwaters. Both gizzard shad and threadfin shad are eaten by striped bass, trout, walleyes, saugers, and other species (Parsons 1957; Pfitzer 1962; Walburg et al. 1971; Deppert 1978; Combs 1979). Threadfin shad have

been stocked in some reservoirs specifically to provide food in the tailwaters for piscivorous fish (Parsons 1957).

225. The number of gizzard and threadfin shad is generally higher in tailwaters than in natural streams due to their movement from reservoirs either over or through dams (Clark 1942; Parsons 1957; Louder 1958; Pfitzer 1962; J. P. Carter 1968a, 1968b, 1969; Walburg 1971). Occurrence of shad in tailwaters appears to be more related to season than magnitude of outflow from the reservoirs (Clark 1942; Parsons 1957; Louder 1958). The presence of impoundments has also increased shad distribution. In Oklahoma, shad became established in a tailwater where they did not appear in the natural stream prior to impoundment (Cross 1950).

226. Dams also affect anadromous members of the clupeid family by acting as barriers to upstream spawning migration (W. R. Carter 1968; Foye et al. 1969). Large numbers of American shad concentrated below a dam in Maryland during spring. Fish kills sometimes occurred when the turbines were shut down during normal peaking operations and dissolved oxygen in the tailwaters was reduced to lethal levels (W. R. Carter 1968). Alteration of operating procedures to provide maintenance flows of 141.6 m^3/sec through each of two turbines has been required to avoid further low-oxygen fish kills. Maintenance of minimum flows has been credited with allowing the survival of American shad in the Russian River in California (Anderson 1972).

Salmonidae (Trouts)

227. The trouts are coldwater fish which were originally found in the Arctic and North Temperate regions. Over the years they have been introduced into suitable waters throughout the world. Many coldwater tailwaters in the United States have been stocked with hatchery trout on a put-and-take basis. Stocking is done at regular intervals throughout the fishing season to maintain a satisfactory sport fishery. Catchable-size trout (150-200 mm long) are usually

stocked because smaller fish often have poor survival to the creel (Vestal 1954).

228. The rainbow trout is the most common salmonid stocked below dams because it is less costly to raise and easier to catch. Other salmonids planted in tailwaters are brown trout, brook trout, and coho salmon. Rainbow trout are usually stocked in the coldwater tailwaters below reservoirs built on warmwater streams. Rainbow trout or other trouts may be stocked or may occur naturally in coldwater tailwaters below reservoirs built on coldwater streams. Discussion here is limited to the rainbow trout because it is the most common trout in tailwaters.

Rainbow trout

229. Habitat. The rainbow trout is native to the streams of the Pacific coast where many varieties or subspecies have developed. The seagoing form is known as the steelhead trout and is believed to be identical to the strictly freshwater rainbow trout. Because of the ease with which eggs of the rainbow trout can be transported, different strains have been distributed throughout the world.

230. This species lives in a variety of habitats, including streams, lakes, and reservoirs. The rainbow trout tolerates somewhat higher temperatures than other trouts but does best in waters that remain more or less continuously below 21.1°C. According to McAfee (1966), the upper temperature limit for the species varies from about 23.9 to 29.4°C, depending on the oxygen content of the water, size of fish, and degree of acclimation. Cold waters discharged from the lower levels of some reservoirs provide adequate tailwater habitat for this species, provided year-round oxygen levels remain above 5 mg/l.

231. Rainbow trout thrive in small to moderately large streams and shallow rivers, with moderate flow and gravel bottoms of the pool-riffle type. They generally prefer riffles and fast-water areas. Depth criteria have not been defined for trout in general; however, the depth of pools and amount of cover appear to be very important in terms of fish size. Gunderson (1968) found that stream sections lacking deep pools and adequate cover contained only fingerling trout, while stream sections with deep pools separated by riffle areas

contained much larger trout. Trout require adequate stream depths for normal intrastream movement. Riffles are extensively used for feeding areas and for movement between pools (Giger 1973). Minimum depth requirements over riffle areas vary with the size of the stream and the trout inhabiting it; however, minimum water depth over riffles should probably not be less than 0.18 m. Giger (1973) listed the optimal pool depth for cutthroat trout as 0.4 to 1.1 m, depending on age and size. Hooper (1973) stated that for trout in general, areas with velocities between 9.1 and 31 cm/sec are preferred for resting.

232. Reproduction. Rainbow trout spawn between early winter and late spring, depending on the genetic strain and stream conditions. The eggs are deposited in a shallow depression dug by the female on a clean gravel riffle. Females deposit between 200 and 9000 eggs in the nest (redd), depending on fish size. After all eggs are laid and fertilized, they are covered with gravel. The incubation period varies with temperature, averaging about 80 days at 4.4°C and 19 days at 15.6°C. Young remain near the hatching site for a while, tending to school at first and then become solitary and more widely distributed.

233. According to Hooper (1973), the optimum spawning temperature for spring-spawning rainbow trout is 11.1°C, but ranges from 7.2 to 15.3°C. Preferred gravel size is 0.6 to 3.8 cm in diameter, and preferred velocities for spawning are between 42.6 and 82.0 cm/sec.

234. Food. Rainbow trout eat a wide variety of foods but depend primarily on drifting insects. A compilation of the findings of many studies indicates that immature and adult aquatic insects (principally caddisflies, mayflies, and dipterans), zooplankton, terrestrial insects, and fish are usually the most significant foods, though their relative importance varies greatly between waters, seasons, and size of fish. Large trout include more fish in their diet. Oligochaetes, mollusks, fish eggs, amphipods, and algae are foods eaten less extensively, but they may be important locally. For example, in upper Lake Taneycomo, below Table Rock Reservoir in Missouri, amphipod crustaceans make up almost 90 percent of the trout diet (Pflieger 1975).

235. Age and growth. Few rainbow trout live beyond 6 years, and life expectancy for most is 3 or 4 years. Longevity is influenced by many interrelated factors. Poor food conditions may result in poor survival after first spawning. Heavy angling pressure may crop most fish before they are 4 years old. This is especially true for fish stocked in tailwaters, where most may be captured during the same year.

236. Maximum size of rainbow trout varies greatly among different environments. In small streams adults rarely reach 205 mm; whereas in large lakes individuals occasionally exceed 13.6 kg. Maximum size depends primarily on growth before attainment of sexual maturity, which in turn is dependent on quantity and quality of available food. Most growth occurs during the first two growing seasons. Growth is fair for fish on a plankton diet, and is best where forage fish are abundant. Growth usually declines after maturity is reached; this decline is especially evident in waters where large forage organisms are lacking.

237. The rate of growth varies seasonally and at different ages, depending on water temperature, strain of trout, feeding conditions, age at maturity, and other factors. For example, in waters with relatively high temperatures throughout the year, such as the tailwaters of some reservoirs in the southeastern United States, growth is fairly constant in all months; whereas, in waters with seasonal temperature changes, growth is slower or ceases in the winter.

238. Hatchery-reared trout reach a length of 205 to 254 mm when about one year old, at which time they are considered large enough to stock. In Lake Taneycomo, Missouri, where conditions for rapid growth are favorable, stocked rainbow trout grow about 19 mm per month (Pflieger 1975). Naturally reared rainbow trout in Minnesota reach 125 mm the first year, 230 mm the second, and 521 mm the fifth year (Eddy and Underhill 1974).

239. The weight of rainbow trout varies greatly at lengths over 380 mm because of differences in feeding conditions and stage of maturity. Fish are heaviest where food is abundant, particularly in

lakes. According to McAfee (1966), weight of fish in average condition by 127-mm fork length groups is as follows:

Length, mm	Mean weight, kg
127	0.028
254	0.227
381	0.568
508	1.589
635	3.178
762	4.767

Most fish spawn by age III; males one year earlier than females. Size at maturity is extremely variable but usually ranges between 254 and 381 mm. In California, mature rainbow trout typically weigh less than 0.45 kg (McAfee 1966).

Rainbow trout in tailwaters

240. Habitat. Trout are found in most tailwaters throughout the United States where summer water temperatures normally do not exceed 21.1°C. They may occur naturally below dams built on coldwater streams or they may be stocked in tailwaters below dams on warmwater streams where hypolimnetic releases maintain coldwater conditions throughout the year. Tailwaters below most deep-release reservoirs have low turbidity, cold temperature, and stabilized seasonal flow, thus providing satisfactory trout habitat. These tailwaters often provide coldwater habitat on streams in areas such as Texas and Arkansas. where trout could not live before dams were constructed.

241. The quantity and quality of coldwater habitat in a tailwater suitable for trout are a function of reservoir design and operation, as well as tailwater physical characteristics. Reservoir features that determine habitat suitability include reservoir stratification, reservoir storage capacity, reservoir storage and release patterns, and intake location. Tailwater features that influence habitat suitability are water temperature, stream channel configuration, stream substrate, stream cover, water depth, water velocity, water quality,

turbidity, and tributary inflow. These factors act in combination with stocking to determine trout abundance and distribution.

242. Numerous fish species are found in association with rainbow trout in many tailwaters. Most compete with the trout for food and habitat. Game fish inhabiting these waters include largemouth and smallmouth bass, bluegills, longear sunfish, and catfish. Brown and brook trout may also occur in the same location. Cyprinids, suckers, sculpins, and sticklebacks are major nongame competitors.

243. Low flow, sometimes aggravated by elevated water temperature, is a common factor limiting trout distribution and abundance in many tailwaters. Low flows can decrease cover, increase overwintering mortality, allow sediment accumulation, and cause stranding. Reduction of flow in a Tennessee tailwater limited habitat to a long shallow pool with bedrock substrate and little cover (Parsons 1957). Kraft (1972) found a 62 percent decrease in brown trout habitat when flow was reduced 90 percent in another site. Weber (1959) found that when annual flow below a reservoir was reduced to 11 percent of the long-term average, trout habitat was reduced 82 percent. Flows that reduce water depth over riffles to 7.6 cm or less make these areas unusable to large trout (Corning 1970). Decreased flows and thus decreased water velocity favor small trout and rough fish over large trout. Low flows also cause a redistribution of trout to less suitable habitat, increasing competition with other fish. Corning (1970) also found that reduced flows concentrate fish in the remaining habitat and intensify predation.

244. In the western United States, irrigation-storage reservoirs collect surface runoff during winter and spring to be used during summer irrigation. Holding runoff decreases stream flows during the winter and spring which can increase trout mortality. Adequate reservoir discharge is critical during winter to sustain a tailwater trout population. The survival of 3-year and older trout was directly related to the magnitude of flow from a reservoir during the winter storage period (Nelson 1977). Vincent (1969) stated that dewatering below a dam in Montana resulted in excessive mortality of young (age I) trout. Studies in Wyoming showed that seasonal minimum flows were

essential for trout survival. Winter flows of 14.2 m^3/sec were recommended to maintain adequate cover for overwintering trout. Spring and summer flows of 22.7 m^3/sec were recommended to select against rough fish and for large trout, and flows of 45.3 m^3/sec were recommended periodically to flush silt from the tailwater. A 30-day survival flow of 8.5 m^3/sec was recommended for times of extreme water shortage (Banks et al. 1974).

245. Low flows in tailwaters allow sediment accumulation in holes and over gravel substrate, thus limiting the quantity of trout habitat. Sediment input into tailwaters is usually from tributary inflow or the erosion of alluvial banks within the tailwater. Reduced spring flows below a dam in Montana increased sediment accumulation by tributary inflow. Timed spring discharges from the dam are used to wash sediment downstream (May and Huston 1979). Seasonal flood flows over the spillway removed sediment from a tailwater in Alaska (Schmidt and Robards 1976). Sediment accumulations behind a dam in California were reduced by periodic flushing into the tailwater, which caused destruction of trout habitat for 1.6 to 3.2 km downstream (Anderson 1972).

246. High flows and flow fluctuations in tailwaters can be limiting factors for certain size classes of trout. Banks et al. (1974) found that water velocity increased sharply with increased dam discharge. Trout 30 cm long or longer were favored over smaller trout and rough fish because of lack of resting cover and high water velocities. High water velocities and sparse cover results in low standing crop (26.1 and 42.6 kg/ha) and harvest (7.7 and 8.6 kg/ha) of trout. The trout that remain are usually large and weigh between 0.7 and 5.5 kg (Mullan et al. 1976).

247. Rapid flow fluctuation below both hydropower and diversion dams has caused stranding of both trout and salmon (Anderson 1972; Kroger 1973; Fowler 1978). Kroger (1973) suggested that decreasing flows at a maximum rate of 2.8 m^3/sec/day would reduce stranding of fish below a dam in Wyoming. However, the most serious effect of flow fluctuations appears to be reduced trout reproduction, rather than a

direct increase in adult fish mortality (Parsons 1957; Baker 1959; Axon 1975).

248. The cold temperature of tailwaters below hypolimnetic release dams built on warmwater streams helps trout to compete effectively with or replace native fish species. Vanicek et al. (1970) found native fish replaced by rainbow trout in the 42 km of river below a dam in Utah and Colorado. Lower water temperatures below a dam in Texas caused partial replacement of 20 native species by stocked rainbow trout (Butler 1973).

249. Dams with hypolimnetic releases built on coldwater streams have altered the habitat by lowering water temperatures and stabilizing flows. Below a Colorado dam, reduced water temperature caused a redistribution of trout species, with brook trout moving into the colder water near the dam (5.0-8.3°C) and brown and rainbow trout moving into the warmer areas downstream. After completion of two Colorado dams, summer water temperatures in the tailwater were reduced by 3.2 to 5.0°C. The temperature reduction is believed responsible for trout appearing in areas where they were previously rare or absent (Mullan et al. 1976). Penaz et al. (1968) stated that the Vir tailwater on the Svratka River, Czechoslovakia, had reduced water temperatures and stabilized flows during the summer, and these conditions favored brown trout over nase, a warmwater species. Nase were reduced from 63.4 to 12.7 percent of the tailwater fish harvest and brown trout increased to 76.8 percent.

250. In addition to reduced maximum temperatures, the seasonal rate of temperature increase is slowed in many cold tailwaters. In a Montana tailwater, the normal spring water temperature of 12.8°C is achieved 6 to 8 weeks later than it was before the dam was built. This change delays the spawning of suckers and gives trout a competitive advantage in the tailwater (May and Huston 1979).

251. Reduced stream flows (usually less than 10 percent average daily flow) during periods of warm air temperature can cause water temperatures to exceed lethal levels for trout. This situation often occurs in natural streams, in tailwaters below deepwater release

reservoirs on formerly warmwater streams, and below hydropower dams that discharge only during periods of high electrical demand. Dendy and Stroud (1949), Parsons (1958), Baker (1959), Kent (1968), Jeen (1974), Axon (1975), Aggus et al. (1979), and others have stated that high water temperatures may limit trout populations in tailwaters. Many reservoirs have incorporated minimum water releases in their operating schedule to maintain suitable flows and water temperatures in tailwaters. The U. S. Bureau of Sport Fisheries and Wildlife (1969) recommended a minimum flow of 7.1 to 11.3 m^3/sec to maintain the trout fishery in a Wyoming tailwater. Suitable trout water temperatures are maintained for 9.7 km below Canyon Dam, Texas, by cold hypolimnetic discharge (Butler 1973).

252. Extremely cold water temperatures were associated with the loss of a trout fishery in several tailwaters. A New Mexico tailwater experienced an 8-month average water temperature decline from 10°C in 1968 to 5°C in 1971. This temperature change was associated with a decrease in trout harvest from 78,656 fish in 1968 to 10,642 in 1971 (Mullan et al. 1976). In a similar situation, an average trout harvest of 109.5 kg/ha was recorded when annual water temperatures ranged from 3.1 to 12.0°C; however, when the average annual temperature range decreased to between 4.2 and 9.2°C, the trout harvest decreased to only 6.2 kg/ha (Mullan et al. 1976).

253. Low dissolved oxygen concentrations and gas supersaturation resulting in nitrogen embolism can cause mortality of trout in otherwise suitable tailwater habitat. Low dissolved oxygen is a problem often encountered in the southeastern United States in tailwaters of deep-release dams built on warmwater streams. This oxygen deficiency occurs when a reservoir thermally stratifies and decomposition of organic matter within the hypolimnion consumes available oxygen. Nitrogen embolism may occur when fish inhabit tailwaters that are supersaturated with atmospheric gases and the body fluids of the fish also become supersaturated.

254. Trout generally prefer water with 5 mg/l or more dissolved oxygen. The species may not survive when hypolimnetic release water

contains little or no dissolved oxygen. The penstock design at some dams does not allow for aeration of hypolimnetic water before release into the tailwaters. Low dissolved oxygen was found to limit the fauna in some tailwaters (Hill 1978). A dissolved oxygen concentration of 0.8 mg/l presumably caused the death of about 100 rainbow trout in an Oklahoma tailwater (Deppert 1978). However, a dissolved oxygen concentration of 2 mg/l in November 1951 in a Tennessee tailwater caused no apparent signs of distress in trout (Pfitzer 1962). Baker (1959) found low dissolved oxygen and distressed fish directly below a dam in Arkansas in the fall. The oxygen concentration returned to normal and fish recovered downstream over the first riffle. Turbulent flows increase the aeration process and thus improve the tailwater habitat by increasing dissolved oxygen concentrations.

55. Gas supersaturation has been a major cause of steelhead and salmon mortality during high-water years in the Snake River, Idaho and Washington (Raymond 1979). Graves and Haines (1969) stated that dead fish with gas bubbles on their fins were found within 1.6 km of a dam in New Mexico on several occasions. Nitrogen supersaturation below a Montana dam persisted for some 30.0 km downstream because flows in the tailwater were not turbulent enough to dissipate the nitrogen. Of 39 rainbow trout held in a cage below this dam, 31 died, presumably of nitrogen embolism (U. S. Bureau of Reclamation 1973).

56. Reproduction. Spawning of rainbow trout has been observed in several cold tailwaters, although survival of eggs and juveniles is low. Trout populations in tailwaters rely on stocking or recruitment from the reservoir above to maintain their populations (Stone 1972). Few self-sustaining tailwater trout populations that support a fishery have been reported in the literature. Spawning may occur in tributaries where local conditions are favorable, but the magnitude of tributary spawning has not been adequate to maintain fishable trout populations in most tailwaters.

57. The harsh environmental conditions (flow fluctuations, dewatering) encountered in tailwaters reduces reproductive success. Corning (1970) found that high flows washed out trout redds. Parsons

(1957) found the 3-m water-level fluctuation in a Tennessee tailwater from October through December detrimental to trout reproduction. Redds were consistently scoured out at high flows and stranded on dry shoals during low flows. Rainbow trout spawning in December and January was common on shoals and riffles in an Arkansas tailwater, but water-level fluctuation caused rolling gravel and destruction of redds. Spawning in tributaries was successful, but the contribution of naturally produced fish to the trout fishery in tailwaters was insignificant (Parsons 1957; Baker 1959; Pfitzer 1962). Low trout populations in the Beaverhead River, Montana, were caused by poor reproductive success due to low flows. Spring and winter dewatering (low flows) of the river caused by irrigation storage reduced egg and larvae survival by decreasing the cross-sectional area and water velocity of the stream (Nelson 1977). Corning (1970) found that low flows exposed trout redds to the air and increased siltation, thus reducing egg survival from 85 percent to only 17 percent. Siltation filled the interstices of the substrate and smothered the eggs. Schmidt and Robards (1976) suggested staged flows in an Alaska tailwater to clean the substrate and increase trout and salmon spawning and rearing habitat.

258. Spawning of trout is common in a Wyoming tailwater, but the lack of cover reduces survival of fry. This tailwater relies on an annual stocking of 348 rainbow trout fingerlings per hectare to maintain the fishery (Mullan et al. 1976). Moffett (1942) recommended stocking of 30,000 fingerling rainbow trout (127 to 178 mm long) per year to compensate for low reproduction caused by water-level fluctuations in a tailwater in Nevada and Arizona.

259. An obvious effect of dam construction is the blockage of fish migration upstream to spawning grounds. Construction of a dam on a California river, impounded [illegible] percent of the salmon spawning area ([illegible] 1949). Attempts to mitigate loss of spawning areas by hatchery construction have been only partly successful, particularly for salmon species ([illegible] 1972). When a hatchery for Baltic salmon was [illegible] the [illegible] tailwater in the U.S.S.R. to replace inundated spawning grounds, [illegible] (196?) argued against the

hatchery because he believed the high number of predators in the tailwater would devastate the yearling salmon. Striped bass and saugers are significant predators on small trout stocked in some tailwaters during certain seasons (Boles 1969; Arizona Game and Fish Department 1972; Deppert 1978).

260. Food. Food studies have been completed on trout from a number of tailwaters and it is apparent that their diet is very diverse (Table 1). *Cladophora* beds are an important food source for trout in tailwaters (Moffett 1942; Mullan et al. 1976). Trout graze on these mats and ingest the algae and the isopods, simuliids, and mayflies harbored therein. In some tailwaters, food organisms have been introduced to provide food for trout. Snails were introduced below Glen Canyon Dam, Arizona, and amphipods were introduced into Taneycomo Lake, Missouri (Table Rock tailwater) (Mullan et al. 1976; Ralph Burress, U. S. Fish and Wildlife Service, personal communication).

261. Trout are not totally dependent on food production within the tailwater. In Dale Hollow tailwater, Tennessee, 81 percent of the organisms in rainbow trout stomachs were cladocerans which were produced in the reservoir above (Little 1967). In this same tailwater, rainbow trout weighing from 1.8 to 2.3 kg ate crappies 102 to 152 mm long which had been stunned when they passed through the dam (Parsons 1957). Rainbow trout below Center Hill Dam, Tennessee, fed heavily on 51- to 76-mm threadfin shad which had passed through the turbines (Parsons 1957). In Wyman tailwater, Maine, rainbow trout over 406 mm long were more piscivorous than smaller trout. Smaller trout ate Chironomidae (dipterans) which were produced in the reservoir and carried into the tailwater (Trotzky 1971).

262. Food organisms eaten by rainbow trout collected below a reservoir differed from that of fish 48.3 km downstream (Welch 1961). Algae were the primary food below the dam, and mayflies and small stoneflies farther downstream. The influence of tailwater flow and temperature on food availability decreases downstream as tributary inflow, meteorological conditions, and other influences moderate the effects of the discharge. Brown trout that were collected immediately

Table 1

Food of Trout in Tailwaters

Tailwater	Food item	Reference
Boulder (Hoover) Nev., Ariz.	Cladophora, mayfly, midge larvae	Moffett 1942
Canyon, Tex.	Ephemeroptera, Diptera, Trichoptera	Butler 1973
Canyon, Tex.	Ephemeroptera, Diptera, Trichoptera, terrestrial insects	White 1969
Center Hill, Tenn.	Threadfin shad	Parsons 1957
Cow Green, U.K.	Ephemeroptera, terrestrial insects, zooplankton from reservoir	Crisp et al. 1978
Dale Hollow, Tenn.	Cladocerans, Diptera, Mollusca, terrestrial insects, isopods	Little 1967
Dale Hollow, Tenn.	Cladocerans	Bauer 1976
Dale Hollow, Tenn.	Algae, gastropods, Chironomidae, terrestrial insects, sow bugs, crayfish	Parsons 1957
Davis, Nev., Ariz.	Detritus	Fast 1965
Flaming Gorge, Utah, Colo.	Algae	Mullan et al. 1976
Fontenelle, Wyo.	Cladophora, fish, Daphnia, copepods	Mullan et al. 1976
Glen Canyon, Ariz.	Algae, cladocerans, introduced snails	Mullan et al. 1976

(Continued)

Table 1 (Concluded)

Tailwater	Food item	Reference
Glen Canyon, Ariz.	Snails	Stone 1972
Granby, Colo.	Diptera, Trichoptera, Ephemeroptera	Weber 1959
Gunnison, Colo. (several on river)	Cladophora, emergent insects	Mullan et al. 1976
Narvskaya, U.S.S.R.	Gammaridae, opossum shrimp, Chironomidae	Barannikova 1962
Navajo, N. Mex.	Midge, black fly, caddisfly, mayfly, grasshopper, beetles, stonefly, dragonfly, snails	Mullan et al. 1976
Navajo, N. Mex.	Diptera, Gastropoda, Plecoptera, Tendipedidae, Ephemeroptera, fish, algae	Olson 1965
Norfolk, Ark.	Isopods, amphipods, crayfish, aquatic insects	Baker 1959
Tiber, Mont.	Simuliidae, algae (Cladophora)	Welch 1961
Wyman, Maine	Trichoptera, mayfly, Diptera, terrestrial insects, Plecoptera	Trotzky 1971

below a reservoir in Colorado ate more dipterans (small-bodied insects) than those collected downstream, which ate primarily trichopterans and ephemeropterans (Weber 1959).

263. Food is rarely limiting on the trout populations in cold tailwaters because of natural food production within the tailwater and food exported into the tailwater from the reservoir above. Food organisms exported from the reservoir display seasonal abundance patterns; quantities available in the tailwater are greater during spring and autumn than during midsummer and winter.

264. Age and growth. Trout growth in tailwaters is variable, generally being comparable to that in reservoirs and often exceeding that in natural streams (Welch 1961; Trotzky 1971). The average length of rainbow trout captured below Blue Mesa Dam, Colorado, increased from 246 mm before impoundment to 285 mm after impoundment (Wiltzius 1978).

265. Rapid growth of rainbow trout stocked in tailwaters has been reported in a number of studies. Mullan et al. (1976) reported that stocked fingerlings averaging 191 mm long grew 76 to 102 mm per year in Glen Canyon tailwater, Arizona; 76-mm fingerlings grew to 254 mm in length in one year in Flaming Gorge tailwater, Utah; and 76-to 127-mm fingerlings grew to 254 to 381 mm in length in Fontenelle tailwater, Wyoming. Rainbow trout fingerlings released at an average length of 83 mm grew 178 mm from July to December in Navajo tailwater, New Mexico (Olson 1965). Stevenson (1975) reported that the average length of rainbow and brown trout below Yellowtail Dam, Montana, increased 152 mm between May and December.

266. The abundance of food organisms coming from a reservoir and of invertebrates produced in the tailwater is associated with rapid growth of trout. Parsons (1957) stated that rainbow trout in Center Hill tailwater, Tennessee, fed on threadfin shad coming through the dam and grew 25 mm per month. The availability of the higher quality food (fish versus insects) in Center Hill tailwater apparently produced the rapid growth. Rainbow trout growth decreased in Dale Hollow tailwater, Tennessee, in 1953 and 1954 when the number of fingerlings stocked was

increased from 20,000 to 30,000. This indicated high utilization of available food in the tailwater. Temperatures in Dale Hollow tailwater, which range from 7.2 to 13.3°C with a maximum monthly variation of 1.7°C, are considered excellent for trout growth (Parsons 1957). Rainbow trout that fed on the large numbers of arthropods harbored in the vegetation in Norfork and Bull Shoals tailwaters, Arkansas, during 1957, grew 23 mm per month. In 1958, when flood flows washed out much of this vegetation, trout growth decreased to 17 mm per month (Baker 1959).

267. Trout growth in tailwaters and other areas has been discussed by several authors. Irving and Cuplin (1956) reported only small differences in growth of native and stocked rainbow trout captured in several Snake River tailwaters:

	Total length, mm	
Age	Native fish	Hatchery fish
I	130	127
II	262	244
III	351	333
IV	467	445
V	488	--

Also, no differences in growth could be shown for rainbow trout taken from tailwaters or impoundments on the Snake River, Idaho. Trotzky (1971) found that rainbow trout in Kennebec River tailwaters, Maine, grew faster than rainbow trout in streams and lakes from other areas of the United States. Large trout have been reported from several tailwaters. Rainbow and brown trout weighing 6.8 kg have been captured in the White River tailwaters, Arkansas (Baker 1959), and trout up to 5.5 kg are common in Fontenelle tailwater, Wyoming (Banks et al. 1974).

268. Reduced water temperature extremes in winter and summer and a more homogeneous temperature regime throughout the year appear to have resulted in year-round growth of rainbow trout in some tailwaters. This conclusion is supported by the inconsistent age readings and lack of annulus formation on scales of trout from some tailwaters (Moffett

1942; Parsons 1957; Pfitzer 1962; Olson 1968). In Watauga tailwater, Tennessee, where winter water temperatures are moderate, year-round growth of rainbow trout averaged 15 mm per month. Little or no fish growth will occur in tailwaters where winter water temperatures are extremely cold.

Esocidae (Pikes)

269. There are four species of the pike family in North America: grass pickerel, chain pickerel, northern pike, and muskellunge. The natural range of the chain and grass pickerels is the eastern United States; whereas, that of the northern pike is north-central United States and Canada, and that of the muskellunge is the Great Lakes states south to Kentucky. Northern pike and muskellunge reach a large size and are highly regarded as game fishes. Both species or their hybrids have been stocked extensively in some reservoirs. The chain and grass pickerel are smaller fish and though chain pickerel provide fishing in some streams, grass pickerel seldom reach catchable size. The pickerels occur in some tailwaters, but they receive little mention in the literature and will not be discussed further.

Pikes

270. Habitat. All pikes have similar requirements in that they prefer clean, quiet-water areas of lakes and streams where there is an abundance of aquatic vegetation. In streams, they prefer cover along the margins in patches of vegetation, beside submerged roots or branches, or in patches of shade. Northern pike are commonly found in a variety of habitats in lakes, reservoirs, and large streams, and muskellunge in lakes and pools and backwaters of slow-moving streams.

271. Reproduction. Pikes spawn in the spring soon after ice-out. They move into marshes or other shallow marginal waters where vegetation is abundant. No nest is built, and eggs are broadcast and abandoned. The adhesive eggs sink and adhere to the bottom or to vegetation. They hatch in 10 to 14 days, and the larvae remain inactive but attached to vegetation for 6 to 10 days or until the yolk sac is

absorbed. Both eggs and young may be stranded if water levels drop in the shallow breeding areas. Studies suggest that spring water levels must remain high for at least a month after pikes spawn to obtain good year-class survival.

272. Food. Pikes are carnivorous, feeding principally on other fishes. They remain motionless near cover and dart out to capture unwary passing prey. Pike larvae eat zooplankton and the larger young eat aquatic insects and small fish.

273. Age and growth. Growth of both the northern pike and muskellunge is extremely rapid. Northern pike average 251 mm long at the end of their first year and 777 mm at the end of their sixth year (Karvelis 1964). The maximum length of males probably does not exceed 760 mm (Threinen et al. 1966). Maximum length of females may exceed 1016 mm, but few survive beyond 12 years. Muskellunge average 267 mm long at the end of their first year and 769 mm at the end of 5 years (Karvelis 1964). Maximum age is about 20 years, and maximum reported length is in excess of 1270 mm. For all species of pike, females grow more rapidly and live longer than males. Most fish are mature when 2 or 3 years old.

Pikes in tailwaters

274. None of the pikes are common tailwaters. They may be found there for several years after construction of a reservoir on rivers where the species occurs naturally or after stocking within the reservoir. They may move upstream into tailwaters from downstream locations at certain times of the year to feed or spawn.

275. Most northern pike and muskellunge found in tailwaters have passed over or through a dam from the reservoir above (Diuzhikov 1961; Hanson 1977; Wiltzius 1978). During or immediatly after the filling of a new reservoir, pike may become common in the tailwater for a short period. Diuzhikov (1961) reported large year classes of pike being p duced in Kuibyshev Reservoir, Volga River, as it was being filled. Many of these fish passed over the dam and congregated in the tailwaters, feeding on the large numbers of small fish that passed over the dam or were blocked during upstream migrations. During the two

to three years following impoundment, up to 40 percent of the number and 90 percent of the biomass of fish caught in the tailwaters were pike. These high catches were followed by a rapid decline in numbers within 5 years (Chikova 1968).

276. The loss of pike from Kuibyshev tailwaters can be attributed to both reduced reproduction in the reservoir and lack of spawning success in the tailwater. Spawning in the tailwater was delayed from early May to late May because of slower warming of water and high daily and weekly water-level fluctuations caused by hydropower production, which further inhibited spawning. Additionally, a seasonal drop in water levels of 4 to 5 m occurred during embryonic development, resulting in massive desiccation of the deposited eggs and larvae (Eliseev and Chikova 1968).

277. A similar situation occurred in Narvskaya tailwaters on the Narva River, where regular, sharp water-level fluctuations due to hydropower peaking activity resulted in the disruption or cessation of pike spawning. This was evident from the large number of adult pike found to be resorbing sexual products (Barannikova 1962). Disappearance of northern pike from the tailwaters below four hydropower impoundments (e.g., Cooke, Five Channels, Foote, and Mio) on the Au Sable River, Michigan, is believed to have been caused by the lack of spawning success in the tailwaters, coupled with a general decrease in productivity of the upstream reservoirs (Richards 1976).

278. Dams have also effectively limited reproduction by blocking movement of fish to their upstream spawning grounds. This occurred on the Middle Fork of the Kentucky River where muskellunge numbers have steadily declined since the construction of Buckhorn Reservoir, Kentucky (Branson 1977).

279. The effects of flow regulation on pike are not limited to the immediate tailwaters of certain dams. Reduced river flows resulting from reservoir filling can affect pike distribution and reproduction hundreds of kilometres downstream. Low winter flows below Bennett Dam on the Peace-Athabasca River in Canada during the filling of Williston Lake threatened the northern pike populations in Lake

Athabasca through severe freezing of shallow-water areas and increased oxygen depletion which caused a winter-kill (Townsend 1975).

280. Similarly, flood control below the Volgograd hydropower facility on the Volga River has affected the northern pike population in the delta on the Caspian Sea far downstream. The low water resulting from spring flood control has shifted the pike's distribution within the delta and has caused a delay in the spawning season from March-April to May and a corresponding decrease in spawning success. The delay in spawning shortened the foraging season, and pike growth rates declined. Additionally, the reduction in numbers of the pike's prime forage species, mainly spring spawning vobla, pike-perch, and bream, resulted in a decrease of its annual food supply (Orlova and Popova 1976).

Cyprinidae (Minnows)

281. The minnow family is the largest of all fish families. Most members are small, but some (carp, squawfish, chubs) attain large size. Minnows are found in all natural waters, but are more common in streams than in lakes or ponds. In streams, they are often more numerous than all other fishes combined. Minnows are efficient in transforming minute aquatic food into sizable food for larger game fishes.

282. As a group, the cyprinids vary greatly in food habits; some feed on insects, some on algae, and some on the organic mud of the bottom; still others are omnivorous. Habitats may include silty, clear, or bog waters; quiet or rapidly flowing streams; sand, mud or gravel bottoms.

283. Spawning migrations by minnows are limited; no species moves more than a short distance upstream, or beyond the shoals of a lake. All spawn in spring or summer and the incubation period of the eggs is relatively short. Some species merely scatter their eggs in a suitable habitat; others deposit them in specially prepared nests; and still others guard the eggs until they hatch.

284. Many different species of minnows often occur in the same waters. In such instances, the various species are found over

different types of bottoms: mud feeders over mud bottom, algae feeders over algae-covered rocks, and insect feeders over sand and gravel or other types of bottoms.

285. With the exception of carp and some chubs, minnows are not sought by sport fishermen. Most minnows are effective baits for the taking of sport fishes. Because of the large number of minnow species, this discussion of life history is limited to the following general cyprinid groups: carp, chubs, true minnows,* shiners, and stonerollers. Species considered within these groups are those most often mentioned in tailwater literature. Discussion of cyprinid occurrence in tailwaters includes the above five groups plus daces, squawfishes and chiselmouths, and cyprinids in Russian tailwaters. Daces, squawfishes, and chiselmouths are of local importance, and Russian cyprinids are included to illustrate tailwater-fish problems similar to those found in the United States.

Carp

286. Habitat. Carp are found throughout the United States. The species is very adaptable and occurs in most aquatic habitats but is most common in large streams, lakes, and man-made impoundments that are highly productive because of natural fertility or organic pollution. In streams, adult carp are usually found near submerged cover such as brush piles or logs and where the current is the slowest. In lakes and reservoirs, carp are usually found near shore or in shallow embayments; an occasional fish may be found in depths exceeding 10 m.

287. Carp do not school, but they do form loose aggregations. The species is not considered migratory, but some individuals move for long distances. Where carp become abundant there is usually a general deterioration of the habitat because of increased turbidity and destruction of aquatic vegetation caused largely by the fish's feeding habits.

288. Reproduction. Carp move into shallows to spawn between late March and late June. Spawning starts at water temperatures of 14.5 to

*Members of the family Cyprinidae whose common name includes the word "minnow" (Bailey et al. 1970).

17°C but peaks at 18.5 to 20°C. The eggs are scattered over logs, rocks, or submerged vegetation. Eggs hatch in 4 to 8 days, depending on temperature; there is no parental care of eggs or fry. Carp often spawn in water so shallow that their backs are exposed and the noise created as they thrash about can be heard for considerable distances.

289. Food. Carp feed on a variety of animal and plant material. Aquatic insects are the most common diet item and plant material ranks second. Most active feeding occurs in late evening or early morning and food is probably located more by taste than by sight. Carp are mostly bottom feeders, but they have also been observed taking floating objects on the water surface.

290. Age and growth. According to Pflieger (1975), carp in Missouri streams average 165 mm long at the end of their first year of life and reach lengths of about 279, [illegible]61, 424, and 457 mm in succeeding years. On the average they weigh 0.45 kg when 305 mm long, [illegible] kg when 5[illegible]6 mm long, and [illegible].4 kg when 69[illegible] mm long. Carp from cool, infertile waters grow more slowly and weigh less at comparable lengths than do those from warm, productive waters. Few live more than 1[illegible] years. Most males are mature at ages II-IV and most females at ages III-V.

Carp in tailwaters

291. Carp are common to abundant in many warmwater tailwaters. They were abundant in the anglers catch in Lake of the Ozarks from 1965 to 1974 and were 6 percent of the catch in 1964 in Clearwater Dam tailwater, Missouri (Hanson 1965, 1977). Carp made up 57 percent of the fish captured by anglers in 19[illegible]8 in Carlyle tailwater, Illinois (Fritz 1969), and constituted the bulk of the weight of fish collected in Holyoke Dam tailwater, Massachusetts (Jefferies 1974). They were also numerous below Fern Ridge Reservoir, Oregon (Hutchison et al. 1966).

292. Carp have also adapted well to conditions in a number of cold tailwaters. Creel surveys in Kentucky on the Barren Reservoir and Nolin Reservoir tailwaters from 1965 through 1971 recorded catches of carp ranging from 1,300 to 6,200 and 143 to 10,000 fish, respectively. These catches accounted for [illegible] to 30 percent of the total

sport fishing catch on these tailwaters during those years (J. P. Carter [illegible]; Charles and McLemore 1973). In addition, carp composed 50 percent of the fish population (estimated from samples collected by [illegible]fishing) in Nolin Reservoir tailwater in March 1966 (J. P. Carter [illegible]). Carp are abundant in Chilhowee and Norris tailwaters, Tennessee (Hill 1978). They are one of the dominant species in Dale Hollow tailwater, Tennessee (Bauer 1976). Though not numerous in the immediate tailwater, carp were found to make up 18 percent of the fish population 42.4 km downstream below Cumberland Dam, Kentucky (Henley 1967). Carp are commonly found in angler catches in a series of tailwaters on the Snake River, Idaho, including Lower Salmon Falls, Bliss, and C. J. Strike (Irving and Cuplin 1956). Holden and Stalnaker (1975) also reported carp as common below Glen Canyon Dam, Colorado. Not all cold tailwaters continue to provide good carp habitat. Carp have decreased in abundance in a Wyoming tailwater, apparently because of declining temperatures (Mullan et al. 1976).

293. Dam construction has limited the distribution of carp. The upstream migration of carp out of some Tennessee reservoirs has been blocked by mill dams. This helps maintain the populations of smallmouth bass and other game fish in these streams by limiting competition (Ruhr 1957). In the Kennebec River, Maine, carp have been kept out of the productive upper river by the presence of Augusta Dam (Foye et al. 1969).

294. Successful carp reproduction may occur in tailwaters, but it has not been verified. Running ripe carp were caught in Lewis and Clark tailwater, South Dakota and Nebraska, at temperatures of 20°C, and spent females were found after temperatures of 25°C were reached. No young-of-the-year carp were collected from this tailwater (Walburg et al. 1971).

295. Most recruitment of carp to tailwaters appears to come from the reservoir above or the river downstream. Large numbers of young-of-the-year carp--as many as 310,000 in 24 hours--were found in the discharge at Lewis and Clark Lake, but these fish did not stay in the tailwater (Walburg 1971; Walburg et al. 1971). Adult carp were the

second most numerous species lost over the spillway at Little Grassy Lake, Illinois, amounting to 14 percent of the total fish transported into the tailwater (Louder 1958).

296. Food habits of carp in tailwaters were examined only below Lewis and Clark Lake. Zooplankton, algae, and bryozoans were all utilized. Zooplankton was the main food available during the period when carp were most abundant, from early spring through July (Walburg et al. 1971).

297. Carp grow well in most warmwater tailwaters. The average weight of carp taken by anglers in Carlyle tailwater, Illinois, was 0.66 kg in 1967 and 0.50 kg in 1968 (Fritz 1969). The average weight of this species collected in Canton Reservoir stilling basin, Oklahoma, was 0.50 kg (Moser and Hicks 1970). Carp collected in Lewis and Clark tailwater averaged 8 percent larger than those from the reservoir (Walburg et al. 1971).

Chubs

298. Habitat. Most species of chubs inhabit clear streams having permanent flow and a predominance of clean gravel or rubble bottoms. Adults are usually found near riffles or in pools but not in the swifter current. The young are usually found in quiet-water areas and most often in association with higher aquatic plants.

299. Reproduction. The following description of spawning by the hornyhead chub (Scott and Crossman 1973) is believed typical for stream chubs. Spawning takes place in the spring of the year, probably when water temperatures reach about 24°C. Nests of stones and pebbles are built by the males on a fine-gravel or pebble bottom, often below a riffle, and in relatively shallow water that covers the top of a completed nest to a depth of 15.2-45.7 cm. Nest building is usually begun after May 15. As construction progresses, females may approach the nest and be enticed to it or driven over it by the male. Spawning takes place in a few seconds and the female moves quickly downstream. The released eggs settle among the stones and the male continues to add more stones to the nest, thus ensuring additional protection for the eggs. The nest-building male carries stones in his mouth or rolls

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and pushes them with lips and snout. The total egg complement is not deposited in one nest at one time, since at each spawning a female deposits only ripe eggs. As many as 10 females may spawn in one nest. The nest mound increases in size as more stones are added by the male after successive spawnings. The sizes of nests are irregular and vary from 30.5 cm to 91.4 cm wide, from 61.0 cm to 91.4 cm long (with the current), and from 5.1 to 15.2 cm deep. The nesting sites may be used as spawning grounds by other species of minnows, even while the chub is still using the nest.

300. Food. Young chubs feed on cladocerans, copepods, and chironomids. Adults eat mainly immature and adult aquatic insects, terrestrial insects, crustaceans, and plant material. Crayfish, worms, and mollusks are also consumed by some species.

301. Age and growth. The ultimate size attained by chubs varies with the genus. Total lengths of adults are generally 65 to 75 mm in some genera and 100 to 200 mm in others. Maximum length ranges from 90 mm for some genera to 260 mm for others. Males grow more rapidly than females and reach a larger maximum size.

Chubs in tailwaters

302. The common name "chub" is used for fish of several genera. This discussion is limited to chubs from the genera *Hybopsis*, *Gila*, *Mylocheilus*, *Nocomis*, and *Semotilus*.

303. The various chubs respond differently in tailwater environments and their presence or absence depends primarily on the characteristics of the particular tailwater. In Tennessee, the river chub (*Nocomis micropogon*) is abundant in the coldwater Apalachia and Chilhowee tailwaters, where it is used as forage by other fish species (Pfitzer 1962; Hill 1978). This chub has disappeared from the Grand River below Shand Dam, Ontario, but it remains common in the river above the reservoir. Delay of the spawning season because of a 7°C decline in maximum temperature, from 28°C above the reservoir to 21°C in the tailwater, is cited as the reason for the river chub's disappearance (Spence and Hynes 1971b). The river chub has also disappeared from the warmwater tailwaters below four hydropower

impoundments on the Au Sable River, Michigan (Richards 1976), but the reason for this disappearance is unknown.

304. The roundtail chub (Gila robusta) is found below Blue Mesa Dam, Colorado, and has apparently suffered no ill effects from the reduced temperature and turbidity in this tailwater (Mullan et al. 1976; Wiltzius 1978). However, this species of chub appears to be disappearing from a tailwater in New Mexico (Mullan et al. 1976). In a tailwater in Utah and Wyoming, the roundtail chub did not reproduce in two of three years following impoundment, presumably because of the reduction of summer water temperature from 8.3 to 2.8°C that resulted from increased summer hypolimnetic discharges in 1964 and 1966. The growth rate of this species has also declined since impoundment (Vanicek and Kramer 1969). The similar bonytail chub (Gila elegans), once considered a subspecies of the roundtail chub, has disappeared from a cold tailwater in Wyoming because water temperatures and turbidities suitable for this species no longer occur (Mullan et al. 1976).

305. The humpback chub (Gila cypha) was occasionally found in an Arizona tailwater in 1967, but by 1973 numbers of this species in this cold tailwater had further declined, most likely because of habitat changes resulting from dam construction and operation (Holden and Stalnaker 1975).

306. The hornyhead chub (Nocomis biguttatus) has a large population in the cold tailwater below Hoover Dam, Ohio, where temperatures range from 14.4 to 21.7°C. Overcrowding in the tailwater may be aiding expansion of this species in the drainage, where it was rarely found before impoundment of the reservoir (Cavender and Crunkilton 1974). Spawning delays caused by the 7°C temperature reduction below Shand Dam, Ontario, have eliminated the hornyhead chub from this tailwater. This species is one of the more common cyprinids above the reservoir (Spence and Hynes 1971b).

307. The creek chub (Semotilus atromaculatus) has thrived in cold tailwaters. It is common in Hoover tailwater, Ohio (Cavender and Crunkilton 1974), and in the tailwater below Granby Dam, Colorado, in spite of a reduction in flows to only 11 percent of the historical

average (Weber [illegible]). Cold water temperatures appear to have aided the creek chub in Shand Dam tailwater, Ontario. The species has continued to reproduce successfully here, whereas the reproduction of other cyprinids has ceased. This has allowed the creek chub to become numerous in the tailwater, although it infrequently occurs above the reservoir (Spence and Hynes 1971b).

308. A 6- to 8-week delay in spawning caused by reduced temperatures has led to a decline in the reproductive success and numbers of the peamouth chub (*Mylocheilus caurinus*) in a Montana tailwater (May and Huston 1979). The peamouth chub occurs and is occasionally creeled in the cold tailwaters below Upper and Lower Salmon Falls dams, Bliss Dam, and C. J. Strike Dam in Idaho (Irving and Cuplin 1956).

309. The streamline chub (*Hybopsis dissimilis*) was collected in Barren Reservoir tailwater, Kentucky, during an electrofishing survey in March 1966 (J. P. Carter 1968a). The speckled chub (*Hybopsis aestivalis*) has disappeared from a cold tailwater in Texas, although it was found in the vicinity of the dam during preimpoundment surveys and still survives in the river above the reservoir (Edwards 1978). Cold water temperatures and other factors in the tailwater, caused by hypolimnetic releases, are most likely responsible for loss of this fish.

310. Reduced turbidity in tailwaters may benefit some chub species. The turbidity-intolerant bigeye chub (*Hybopsis amblops*) is occasionally found in Hoover Dam tailwater, Ohio, perhaps due to relatively lower turbidity levels. This species is seldom found in the rest of the Big Walnut Creek drainage (Cavender and Crunkilton 1974).

311. Because of the large number of chub species and the wide range of their environmental requirements, generalizations on their success in tailwaters is difficult. Temperature changes and their effects on reproduction, along with changes in turbidity, appear to be most important in determining the presence or absence of chubs.

True minnows

312. Habitat. The true minnows are a diverse group with a variety of habitat preference. Many prefer lakes, ponds, or backwaters of

slow-moving streams with dense vegetation. Few species are found in reservoir tailwaters. They are tolerant of turbidity as long as there is enough current to keep riffle areas free of silt. Many occur in schools near the river bottom, but they avoid strong current.

313. Reproduction. Most minnows spawn between April and July. Some randomly spawn in shallow areas above gravelly or sandy riffles and others over silt bottoms; still others prepare nests in sand or gravel areas which are guarded by the male. The following description for the bluntnose minnow (*Pimephales notatus*) taken from Pflieger (1975) is fairly typical for nest-building minnows.

314. The bluntnose minnow has a long spawning season, extending in Missouri from early May, when water temperatures are at least 20°C, to about mid-August. The peak of spawning is in late May and June. The eggs are deposited on almost any object (flat stones, boards, logs) that has a flat undersurface and lies on the bottom at depths of 15 to 90 cm. Usually sand or gravel, rather than a mud bottom, is selected for a nest site. Nest construction consists of excavating a small cavity beneath the object selected and cleaning the undersurfaces where the eggs will be deposited. In excavating the cavity, silt, fine sand, and pebbles are swept away by violent motions of the tail fin, and larger objects are pushed out with the tuberculate snout. The roof of the cavity is cleaned by the male with his mouth and the spongy pad on his back. Only a single male occupies a nest, but several males often nest in proximity beneath a single object. Several females may spawn in a single nest, which may ultimately contain more than 5000 eggs. Eggs hatch in 6 to 14 days, depending on water temperature, and newly hatched young are about 5 mm long. The male remains on the nest throughout the incubation period, driving away all other fish except females ready to spawn.

315. Food. The food of the minnows is generalized and includes both plants and animals; aquatic insects, small crustaceans, and algae predominate.

316. Age and growth. Lengths of adult minnows generally range between 50 and 75 mm, and maximum lengths between 75 and 100 mm. Most

average about 50 mm long at end of first year of life and 75 mm at the end of the second. Few live longer than 3 years. Most are sexually mature in their second summer.

317. Males grow more rapidly and to a larger size than females for minnow species in which males guard the nest. Females are usually larger in species that do not guard the nest.

True minnows in tailwaters

318. Seven genera of Cyprinidae are commonly termed "minnows" (Bailey et al. 1970). Two genera (Pimephales and Phenacobius) that reportedly occur in tailwaters are discussed in this section.

319. The fathead minnow (Pimephales promelas) has a wide temperature tolerance which makes it well-suited to the tailwater environment. It has increased in numbers in both the Navajo tailwater, New Mexico, and the Fontenelle tailwater, Wyoming (Mullan et al. 1976). The fathead minnow is one of the remaining native species in cold Granby Dam tailwater, Colorado, where flows are only 11 percent of the historical average (Weber 1959). The fathead minnow is the third most abundant species in the warm tailwater below Lake Carl Blackwell, Oklahoma, and spawning activity was indicated in mid-April when water temperatures reached 17°C (Cross 1950). The fathead minnow also occurs in Hoover tailwater, Ohio. It apparently passed over the dam from the reservoir above where it had been introduced as a bait fish (Cavender and Crunkilton 1974). This species was also introduced into Dale Hollow tailwater, Tennessee, probably through its use as a bait fish (Bauer 1976).

320. The success of the bluntnose minnow (Pimephales notatus) in cold tailwaters is varied. It is found in the cold Barren Reservoir tailwater, Kentucky (J. P. Carter 1968a) and is common in the drainage of Big Walnut Creek, Ohio, including Hoover Dam tailwater (Cavender and Crunkilton 1974). The bluntnose minnow has disappeared from the Grand River below Shand Dam, Ontario, presumably because of lack of spawning caused by temperature reductions, since the species is commonly found in the drainage above the reservoir (Spence and Hynes 1971b).

81. The bullhead minnow (*Pimephales vigilax*) was present in the cold tailwaters below Canyon Dam, Texas, in 1976, but was not collected from the river above the reservoir. No explanation was apparent for the absence of this species in the 1976 collections above the reservoir since it had been collected here in other years (Edwards 1978).

82. Adult suckermouth minnows (*Phenacobius mirabilis*) were abundant in the river below Lake Carl Blackwell, Oklahoma, only during the spawning season. Females in spawning condition occurred in pools below the dam in April at water temperatures of 14 to 25°C. Young of the year were abundant by mid-June in shallow running water. By mid-July, young suckermouth minnows had reached a length of 41 mm and were only found in the swiftest flowing waters below the dam (Cross 1950).

83. In three papers on tailwaters, minnows were referred to in only general terms, without actual species being indicated. Pfitzner (1967) noted a general loss of minnow species in the cold tributary tailwaters of the Tennessee Valley. Diversity of minnow species decreased following the completion of a hypolimnetic release dam in Wisconsin in 1967. Although 8 to 10 minnow species were present at the three study stations below the dam from 1965 to 1968, only 4 to 6 species were found in 1969. Also, there was a decrease in the overall abundance of minnows in this tailwater (Wirth et al. 1970). The authors gave no reason for the observed minnow population changes, although it would appear that cold water temperatures were responsible. Minnows were numerous in the warm tailwater below Elephant Butte Dam, New Mexico, where they made up 57 percent of samples collected in 1956 in seines and by electroshocking (Huntington and Navarre 1957).

Shiners

84. *Habitat.* Shiners (*Notropis*) are the most abundant species within the Cyprinidae. They are a diverse group and the various species have a wide variety of habitat preferences. Many are found only in lakes, ponds, or backwaters with little current, and others largely in small headwater streams. Relatively few shiner species are found in tailwaters. Shiners in tailwaters prefer moderate to large-sized streams with relatively clear water throughout most of year,

moderate or high gradients, and clean sand, gravel, rubble and or boulder-strewn bottoms. Some species are found in the deep, swift riffles and in eddies and currents of pools immediately below such riffles. Other shiners prefer low to moderate current gradients and are most abundant in shallow sandy pools. Some are found in schools in midwater or near the surface, and others near the bottom.

325. Reproduction. Shiners have varied spawning habits depending on the species. The following description for the common shiner taken from Scott and Crossman (1973) is generally applicable to most shiners.

326. Spawning usually begins when water temperatures reach 15.6 to 18.3°C, usually in May or June. Spawning may occur over gravel beds in flowing water; the fish may excavate shallow nests in gravel in flowing water, or they may use the nests made by other fishes, even though such nests lack a current flow. They often spawn at the head of a gravelly riffle where the male establishes a territory. The females stay on the gravel below the males until ready to spawn, then move upstream and eventually spawn. The spawning act takes place in a fraction of a second and is repeated many times, often within a few minutes, and there may be a constant succession of males and females moving onto the spawning site, spawning, and dropping back. Studies suggest that few eggs, probably not more than 50, are released at each spawning. The adhesive eggs drop to the bottom and become lodged between crevices of gravel. Eggs hatch in about 2-1/2 days at 21.1°C and larvae are about 5 mm long.

327. Food. Shiners have generalized food habits. They feed on aquatic and terrestrial insects, small crustaceans, and algae. Larger individuals may prey on small fish.

328. Age and growth. Average length of adult shiners is variable by species. Adults of some species range between 45 and 65 mm long and reach a maximum length of 70 mm; adults of other species range between 75 and 125 mm long and reach a maximum length of 175 mm. Males are the larger in some species, and females in others. Most shiners mature in their second or third summer; few live beyond age III.

Shiners in tailwaters

329. The shiners are a varied taxonomic group with many species. The majority discussed in this section are members of the genus Notropis; however, two shiners from the genera Notemigonus and Richardsonius are also included.

330. The rosyface shiner (Notropis rubellus) appears to thrive in cold tailwaters. It is abundant in Bull Shoals tailwater, Arkansas (Brown et al. 1968; Hoffman and Kilambi 1970), and is favored in the tailwater environment below Hoover Reservoir, Ohio, by both the reduced temperature and the abundance of well-developed riffles (Cavender and Crunkilton 1974). This species, together with the blackchin shiner (Notropis heterodon) and redfin shiner (Notropis umbratilis), has disappeared in the warm tailwaters below four hydropower facilities on the Au Sable River, Michigan (Richards 1976).

331. The mimic shiner (Notropis volucellus) has become a common species below the same four hydropower impoundments on the Au Sable River (Richards 1976). This shiner has disappeared from the cold Canyon Dam tailwater in Texas, although it is common in the river above the reservoir (Edwards 1978).

332. The redside shiner (Richardsonius balteatus) does well in both warm and cold tailwaters. It thrives in water temperatures up to 26.7°C, which occur in tailwaters below dams on the Row River, Long Tom River, and Coast Fork Willamette River in Oregon (Hutchison et al. 1966). It is abundant in the cold tailwaters below Owyhee Reservoir and Antelope Reservoir, Oregon (Fortune and Thompson 1969). It also appears to be maintaining its abundance in the cold Fontenelle tailwater, Wyoming (Mullan et al. 1976).

333. The red shiner (Notropis lutrensis) is found in both warm and cold tailwaters. It is the most abundant species in Lake Carl Blackwell tailwater, Oklahoma (Cross 1950). Below Canyon Dam, Texas, it is the third most abundant species. Edwards (1978) believes that stabilization of water flows below this dam has increased red shiner abundance.

334. The golden shiner (Notemigonus crysoleucas) and the spottail shiner (Notropis hudsonius) are numerous in warm Holyoke Dam tailwater, Massachusetts (Jefferies 1974). In cold tailwaters, the golden shiner is found primarily due to its introduction as a bait fish. It is found in Dale Hollow tailwater, Tennessee, and appears to have moved from the reservoirs into both Hoover tailwater, Ohio, and Canyon Dam tailwater, Texas (Cavender and Crunkilton 1974; Bauer 1976; Edwards 1978).

335. Large numbers of young emerald shiners (Notropis atherinoides)--up to 800,000 in 24 hours--were lost in the discharge from Lewis and Clark Lake, South Dakota (Walburg 1971). In the tailwater, this species is widely used as forage by game fish (Walburg et al. 1971). This species composed 16 percent of the fish taken in Buckhorn tailwater and was also taken from Barren Reservoir tailwater, Kentucky, in an electrofishing survey (Henley 1967; J. P. Carter 1968a).

336. The success of the spotfin shiner (Notropis spilopterus) in cold tailwaters is varied. It occurs commonly in both Hoover tailwater, Ohio, and Barren Reservoir tailwater, Kentucky (J. P. Carter 1968a; Cavender and Crunkilton 1974). This shiner has disappeared below Shand Dam in Ontario due to a delay in spawning caused by cold water temperatures (Spence and Hynes 1971b).

337. A large number of other shiner species occur in cold tailwaters. The duskystripe shiner (Notropis pilsbryi) is the most abundant cyprinid in Norfork tailwater, Arkansas. This species, along with the bigeye shiner (Notropis boops) and the whitetail shiner (Notropis galacturus), is abundant in Bull Shoals tailwater, Arkansas (Brown et al. 1968; Hoffman and Kilambi 1970). In Hoover tailwater, Ohio, the striped shiner (Notropis chrysocephalus) is abundant, while a species not found upstream, the sand shiner (Notropis stramineus), is common. Two other species, the rosefin shiner (Notropis ardens) and the silver shiner (Notropis photogenis), are rare in Hoover tailwater, although they are common in the headwater streams above the reservoir (Cavender and Crunkilton 1974). The silver shiner was also found in electroshocking samples in Barren Reservoir tailwater, and the common shiner (Notropis cornutus) was taken from both Barren

[illegible] in [illegible] Reservoir tailwaters, Kentucky (J. L. Carter [illegible]). Pitman (197[illegible]) [illegible] the blacktail shiner (*Notropis venustus*) [illegible] Texas shiner (*Notropis amabilis*) in [illegible] Dam tailwater, Texas. [illegible] there was no [illegible] in abundance of the Texas shiner, the blacktail shiner was [illegible] below the dam than in the stream [illegible], presumably because of colder temperatures in the tailwater. [illegible] the [illegible] shiner (*Notropis [illegible]*) in [illegible] Dale Hollow tailwater, [illegible].

Stoneroller

[illegible]. Habitat. This fish is most abundant in streams having [illegible] gradients, well-defined gravel, rubble, or bedrock riffles, and permanent flow. It is generally found on riffles or in [illegible], rocky pools where riffles and pools alternate in rapid succession. It [illegible] of turbidity.

[illegible]. Reproduction. The stoneroller spawns earlier in the spring than most other minnows. Spawning occurs on riffles where water may be [illegible] deep. The eggs are deposited in shallow pits dug by the males. Females remain in deeper water near the spawning area, entering the pits individually or in small groups to deposit their eggs. Spawning [illegible] against the female. The adhesive eggs become [illegible] in the gravel and are abandoned before they hatch. Eggs hatch in [illegible] h [illegible] °C. According to Smith (1935), nest building in [illegible] started in mid-April, when water temperature was [illegible], and spawning continued until early June, when temperatures were between [illegible] and [illegible] °C.

140. Food. The stoneroller lives in schools near the bottom. It feeds primarily on algae and detritus that it scrapes from rocks, logs, and other submerged objects with the bladelike extension of its lower jaw.

141. Age and growth. Adult stonerollers are commonly 75 to 165 mm long, and maximum length is about 200 mm. In Missouri, they commonly reach a length of about 35 to 60 mm by late August of the first summer of life (Pflieger 1975). Maturity is reached in the second or

third summer. Males grow more rapidly than females and attain a much larger size.

Stonerollers in tailwaters

342. The stoneroller is reported in a number of cold tailwaters. It was the most abundant species collected in Beaver tailwater, Arkansas. It is also commonly found in the tailwaters of Bull Shoals Reservoir and Norfork Reservoir in Arkansas (Brown et al. 1968; Bacon et al. 1969; Hoffman and Kilambi 1970). The stoneroller is abundant in Apalachia tailwater, Tennessee (Hill 1978), and is also found in other tailwaters of the Tennessee Valley system, where it is used as forage by game fish (Pfitzer 1962). Stonerollers were also taken in electrofishing samples from Nolin tailwater, Kentucky (J. P. Carter 1968a). The shallow gravel-bedrock substrate and 14.4 to 21.7°C temperatures have favored the stoneroller in Hoover tailwater, Ohio. Large numbers of stonerollers spawn in the shallow riffles below the dam and both adults and young are found in this tailwater throughout the year (Cavender and Crunkilton 1974).

Daces in tailwaters

343. Members of seven genera of cyprinids are referred to by the common name "dace." Only two genera, Phoxinus and Rhinichthys, comprising four species, have been reported in tailwaters.

344. The speckled dace (Rhinichthys osculus) appears to do well in some western coldwater tailwaters. It is abundant below Owyhee Dam and Antelope Reservoir, Oregon (Fortune and Thompson 1969). This species has survived below Blue Mesa Dam, Colorado, and has increased in Fontenelle tailwater, Wyoming (Kinnear 1967; Mullan et al. 1976).

345. The longnose dace (Rhinichthys cataractae) has survived in some cold tailwaters. It is commonly found below Owyhee Dam and has survived below Granby Dam, Colorado (Weber 1959; Fortune and Thompson 1969). It has disappeared from the warm tailwaters below four small hydropower dams on Michigan's Au Sable River (Richards 1976).

346. Two other species of dace have been reported from cold tailwaters. The southern redbelly dace (Phoxinus erythrogaster) occurs in pools below Norfork Dam, Arkansas (Brown et al. 1968), and the

blacknose dace (Rhinichthys atratulus) in the headwater streams of Big Walnut Creek, Ohio, and occasionally downstream in the Hoover Dam tailwater (Cavender and Crunkilton 1974).

Squawfishes and chiselmouths in tailwaters

347. Squawfishes and chiselmouths are found only in western North America. The northern squawfish thrives in the warm (up to 26.7°C) tailwaters below Cottage Grove Reservoir, Dorena Reservoir, and Fern Ridge Reservoir, Oregon (Hutchison et al. 1966). This species also appears to do well in most cold tailwaters. It, together with the chiselmouth, is abundant below both Owyhee Dam and Antelope Reservoir in Oregon (Fortune and Thompson 1969). Both the northern squawfish and the chiselmouth are commonly creeled in a series of tailwaters on the Snake River, Idaho, including Upper Salmon Falls, Lower Salmon Falls, Bliss, and C. J. Strike (Irving and Cuplin 1956). A decrease in temperature and a resultant 6- to 8-week delay in spawning is believed responsible for a reduction in northern squawfish numbers in a Montana tailwater (May and Huston 1979).

348. The Colorado squawfish appears to have been affected more than the northern squawfish by dam construction. The Colorado squawfish has disappeared from a cold tailwater in Wyoming (Mullan et al. 1976) and it is no longer found in a 105-km stretch of the Green River in Utah and Colorado (Vanicek et al. 1970). Temperature reductions and alterations in normal flows may have eliminated it. It still survives further downstream, but the alteration of seasonal temperature patterns since impoundment has reduced its growth rate (Vanicek and Kramer 1969). Spawning migrations of Colorado squawfish in the Gunnison River in Colorado have been disrupted by lowered temperatures and reduced spring and summer flows (Wiltzius 1978).

Cyprinids in Russian tailwaters

349. Dam construction and operation in the Soviet Union have affected many species of cyprinids. Historically, the bream was the predominant species of cyprinid in the Volga River in the vicinity of the Kuibyshev Reservoir hydropower dam (Diuzhikov 1961). Shortly after dam closure, the bream, together with the bleak, white bream, and roach

(all cyprinids), were still numerous in the tailwater. However, unfavorable reproductive conditions in the tailwater caused by water temperature reductions, large diurnal water-level fluctuations, and a severe decline in spring flood flows, soon resulted in a decrease in abundance of all cyprinids (Sharonov 1963; Chikova 1968). Ide eggs, laid in the shallows, were lost through desiccation due to fluctuation in reservoir releases. Reduced temperatures in the tailwater delayed the spawning of bream, white bream, and zope. Between 24 and 50 percent of the females of these three species were found to be resorbing eggs in 1963 and 1964 (Eliseev and Chikova 1968).

350. Decreased spring flood flows below the Volgograd hydroelectric facility have disrupted spawning conditions hundreds of kilometres downstream in the Volga Delta on the Caspian Sea. Spring spawning bream and carp have declined in abundance. However, the stabilization of flows throughout the year below this dam have improved the reproductive success of the summer spawning white bream (Orlova and Popova 1976).

351. A reduction in mean water temperature of 4 to 5°C has affected many cyprinid species in the tailwater below Mingeshaur Hydroelectric Dam on the Kura River. Combined fyke net catches of gudgeon, bleak, podust, khramulya, and barbel (all cyprinids) have declined from 73 percent before impoundment to only 40 percent after impoundment. In fact, the barbel and the bystryanka, have completely disappeared. Thirty percent of the catch is now composed of vobla, bream, and carp which have moved downstream into the tailwater from the reservoir above. The altered temperature regime has also shifted the spawning activity of the shemia from early summer to autumn. This shift in activity has not affected spawning success, however; large numbers of shemia larvae and fry are still found in the tailwater (Abdurakhmanov 1958).

352. Reproduction of some cyprinid species has been disrupted by the large flow fluctuations occurring below Narvskaya Hydroelectric Dam on the Narova River. The spawning areas of the vimba have been severely altered because of flow fluctuations, while the fry and eggs of the

golden shiner (European) have been destroyed through the dewatering of large sections of river bottom. Consequently, the numbers of both species have declined (Barannikova 1962).

Catostomidae (Suckers)

353. The sucker family is largely restricted to North America. Suckers are one of the dominant groups of large fishes in fresh water, and in streams their total weight often exceeds that of all other fishes combined. In number of species and individuals, they rank second only to the Cyprinidae. Each group of suckers has specific habitat preferences, and most are bottom dwellers with similar but not identical diets. All feed to some extent on larval and adult aquatic insects, small mollusks, small crustaceans, worms, and algae. All suckers spawn in spring and none build a nest; eggs are scattered in suitable habitat and abandoned. Preferred habitat of the various species ranges from high, cold mountain lakes and swift mountain streams to warm, quiet ponds and lakes.

354. Most suckers are captured during spring spawning runs by use of gigs and snags; few are captured by hook and line. Large numbers of some species are taken by commercial fishermen. The flesh of suckers has good flavor, but numerous small bones detract from its value as food. Small suckers are an important source of forage for game fishes.

355. Those catostomids that commonly occur in tailwaters will be discussed under three groups--buffaloes, suckers, and redhorse.

Buffaloes

356. Habitat. The three buffalo species, bigmouth, smallmouth, and black, have similar habitat requirements. They occur primarily in the deeper pools of large streams, natural lowland lakes, and man-made impoundments. Buffaloes sometimes enter small streams to spawn, and the young may remain here during their first summer of life. Their distributional relation suggests that the bigmouth buffalo is more tolerant of high turbidity than the other two, and that the black buffalo occurs most often in strong currents.

357. Reproduction. The spawning habits of buffaloes are not well known. Buffaloes have been observed spawning in shallow-water areas of rivers and reservoirs with a water temperature range of 15.6 to 18.3°C, between April and June. The adhesive eggs are broadcast into the water, where they settle and adhere to the substrate--e.g., rocks and flooded vegetation. Spawning occurs in water so shallow that the backs of fish are often exposed. The eggs hatch in 9 to 10 days at a water temperature of about 16.7°C.

358. Food. Studies by McComish (1967) and others revealed that all ages of bigmouth buffalo feed principally on zooplankton. The large, terminal mouth and numerous slender gill rakers are efficient devices for straining zooplankton from the water.

359. Zooplankton and attached algae were the principal foods found in smallmouth buffalo stomachs (McComish 1967). This species is primarily a bottom feeder, as indicated by the high frequency of insect larvae, attached algae, and associated detritus and sand in the stomachs. The diet of the black buffalo is assumed to be similar to that of the smallmouth buffalo.

360. Age and growth. The bigmouth is the largest buffalo species. Adults are commonly 380 to 690 mm long and weigh 0.9 to 6.3 kg. Weights of 13.6 kg are not uncommon. Smallmouth and black buffaloes are somewhat smaller than the bigmouth.

361. Buffaloes are long-lived, many living more than 10 years. Females grow larger than males. According to Schoffman (1943) the average lengths and weights reached by the bigmouth buffalo in Reelfoot Lake, Tennessee, through the first eight summers of life were as follows:

Age in summers	Length, mm	Weight, kg
2	335	0.7
3	386	1.0
4	424	1.1
5	455	1.4
6	528	2.4
7	597	3.4
8	668	6.2

362. Growth in weight increases progressively during the first eight summers, indicating that fish in their eighth summer are still in a fast-growing period of life.

Buffaloes in tailwaters

363. Buffaloes inhabit primarily lakes or large rivers and generally are not important in tailwaters. In most instances where buffaloes are found in tailwaters, they have migrated into the area from the downstream reservoir or river.

364. Smallmouth and bigmouth buffaloes are common summer inhabitants of Lewis and Clark Lake tailwaters in South Dakota and Nebraska. Fish collected in June had already spawned, and it was assumed that their presence in the tailwater was related to feeding activity (Walburg et al. 1971). The increase of smallmouth buffaloes in Dale Hollow tailwater, Tennessee, was attributed to their migration upstream from Cordell Hull Reservoir (Bauer 1976). Buffaloes are important in the smaller Rough River tailwater in Kentucky where they made up 9.3 percent of the fish catch by weight (Henley 1967). This tailwater differs from most because it is essentially a long pool created by a mill dam 9.7 km downstream. These pondlike conditions closely duplicate the preferred lentic habitat of the buffaloes.

365. The shallow, fast water in most tailwaters, coupled with a lack of recruitment, severely curtails or eliminates buffalo populations in most tailwaters. Black buffaloes were important in an Oklahoma tailwater shortly after impoundment but were unable to sustain

themselves. This was reflected by the rapid decline from 15 to 6 percent of total catch within 2 years (Hall 1949; Hall and Latta 1951).

366. The food of buffaloes in tailwaters has not been studied extensively. Walburg et al. (1971) found that bigmouth buffaloes from Lewis and Clark Lake tailwater fed almost exclusively on zooplankton in the reservoir discharge, and smallmouth buffaloes fed on both zooplankton in the discharge and on attached algae and bryozoans found in the tailwater.

Suckers

367. A number of sucker species occur in tailwaters. Most commonly mentioned in the literature are the northern hog sucker, spotted sucker, river carpsucker, quillback carpsucker, white sucker, longnose sucker, flannelmouth sucker, bluehead sucker, and largescale sucker. The first four species are generally eastern or midwestern United States in distribution, and the last four are extreme northern or western. The white sucker is more widely distributed, except in the West and South. Description of life history will be limited to the northern hog sucker, spotted sucker, river and quillback carpsuckers, white sucker, longnose sucker, and largescale sucker. Description of tailwater distribution includes all nine of the suckers mentioned above plus several other less common species.

368. Habitat. The northern hog sucker is an inhabitant of moderate-sized streams that have clean gravel or rock bottoms and permanent flow. It is usually found on the stream bottom in riffles or in pools with noticeable current. The heavy bony head, slender tapering body, enlarged pectoral fins, and reduced swim bladder permit it to maintain a position in swift currents with little effort. The northern hog sucker is nearly invisible on the stream bottom because of its strongly mottled a[illegible] barred coloration.

369. The spotted sucker lives in lakes, overflow ponds, sloughs, oxbows, and clean sluggish streams with sandy, gravelly, or hard clay bottoms without silt. It seems intolerant to turbidity, pollutants, and clay-silt bottoms.

370. Carpsuckers are common in large rivers, where they prefer deep, quiet pools and backwaters with moderate or low gradients. The river carpsucker prefers turbid waters with soft bottoms, while the closely related quillback is found in clearer waters with firm bottoms.

371. White sucker habitat is extremely varied, since the species occurs in both lakes and streams with low and high temperatures, low and high turbidities, and fast and slow currents. The white sucker has found man-made impoundments suitable, and has become abundant in some. This species is especially characteristic of headwater streams.

372. The longnose sucker occurs in the cold, clear water of both lakes and streams. Its occurrence in streams is usually related to spawning activity.

373. Largescale suckers live in lakes and in large rivers. They are often numerous in the weedy shoreward areas of lakes, in backwaters, and in stream mouths. This species and the longnose sucker are often found together in the same general habitat.

374. Reproduction. The northern hog sucker spawns during spring near the heads of gravelly riffles in water 8 to 13 cm deep, when water temperature reaches 15.6°C. Each female is attended by one or more males. The demersal, nonadhesive eggs are deposited in a depression on the stream bottom and abandoned.

375. The spotted sucker spawns on riffles above large pools during the spring when water temperature ranges between 15 and 18°C. The eggs hatch in 7 to 12 days, depending on temperature.

376. Carpsuckers are shallow-water, random spawners. They spawn in the spring when water temperatures reach about 21°C. Eggs are dispersed into the water column where they eventually settle to the stream bottom and adhere to the substrate.

377. White suckers spawn in the early spring. Adults usually migrate from lakes into gravelly streams when stream temperatures reach 10°C, but they are also known to spawn on lake margins, or quiet areas in the mouths of blocked streams and in tailwaters. Spawning sites are usually in shallow water with a gravel bottom, but they may also spawn in rapids. No nest is built; eggs are scattered and adhere to the

gravel or drift downstream and adhere to substrate in quieter areas. Eggs hatch in about 2 weeks, depending on temperature, and the young remain near the hatching site for about 2 weeks before moving to quiet areas along the stream bank or in a downstream lake. At this time, they are 12 to 17 mm long.

378. Longnose suckers spawn in the early spring in streams where available, but otherwise in shallow areas of lakes. They enter spawning streams as soon as the water temperature exceeds 5°C. The spawning run for this species reaches a peak several days before the run of white suckers into the same stream. Spawning often takes place in stream water 15.2 to 27.9 cm deep, with a current of 30 to 45 cm/sec, and a bottom of gravel 5 to 10 cm in diameter. No nest is built; the adhesive, demersal eggs are laid in small numbers and adhere to the gravel and substrate. Hatching and emergence of fry is similar to that reported for the white sucker.

379. Largescale suckers spawn in spring, usually in deeper sandy areas of streams where current is strong, but sometimes on gravelly or sandy shoals in lakes. They enter spawning streams when water temperature is 7.8 to 8.9°C and spawn a week or more later than the white sucker, in the same streams. Spawning activity and hatching and emergence of fry is similar to that reported for white suckers.

380. Food. The northern hog sucker is an active feeder, overturning rocks and stirring up the bottom as it forages for immature aquatic insects and other bottom life with its fleshy, sucking lips.

381. The food of the spotted sucker is said to consist mostly of mollusks and insect larvae.

382. Carpsuckers browse extensively on attached filamentous algae. Other diet items include aquatic insects, worms, and mollusks.

383. White suckers have rather generalized food habits but subsist mostly on immature aquatic insects.

384. The diet of longnose suckers consists almost entirely of algae, chironomid larvae, amphipods, and other bottom organisms. Food of young fish includes immature aquatic insects, copepods, cladocerans, and algae.

385. The diet of the largescale sucker consists almost entirely of bottom organisms such as aquatic insects, crustaceans, snails, and algae.

386. Age and growth. According to Pflieger (1975), northern hog suckers in Missouri streams reach a length of about 85 mm by the end of their first year of life and average 165, 246, 300, and 330 mm in their second through fifth years. Females grow more rapidly than males after the fifth year and attain a larger maximum size. Males mature at age II and females at age III.

387. In Oklahoma, the spotted sucker attains a length of about 155 mm in its first year and averages 287, 338, 409, and 439 mm at the end of succeeding years. Maturity is reached at 3 years of age, and the maximum life span is about 5 years (Jackson 1957).

388. According to Pflieger (1975), river carpsuckers in Missouri average 81 mm in length by the end of their first year of life and 165, 229, 312, and 348 mm in succeeding years. Maximum life span is at least 10 years. Average annual growth of the quillback carpsucker is slightly greater than that of the river carpsucker.

389. In Missouri, the white sucker averages 97 mm in length by the end of its first year of life and 173, 229, and 297 mm in succeeding years. Maximum length is about 508 mm. Fish mature when 3 or 4 years old; males mature a year earlier than females.

390. According to Brown (1971), longnose suckers in Montana average 76 mm by the end of the first year of life and 140, 216, 267, 318, and 432 mm in succeeding years. The largest individual reported for Montana was 564 mm long and weighed 2.2 kg. Fish mature at 4 or 5 years of age.

391. Growth of largescale suckers is generally slow. According to Brown (1971), growth in Montana averages 51 mm by the end of the first year of life and 89, 140, 190, and 254 mm in succeeding years. Specimens as old as 11 years have been reported. This sucker matures when 4 or 5 years old.

Suckers in tailwaters

392. The effects of tailwaters on suckers have been varied, depending on the type of tailwater and the species of sucker. Taken as a group, suckers compose a significant segment of the fish population in many tailwaters.

393. The northern hog sucker is abundant in many eastern coldwater tailwaters. Pierce (1969) found no change in the numbers of hog suckers below Summersville Dam in West Virginia following closure. Hog suckers have remained extremely abundant in Chilhowee tailwater, Norris tailwater, and Apalachia tailwater in the Tennessee Valley, where young of the year are used as a food source by game fish (Pfitzer 1962; Hill 1978). The lower water temperatures (14.4-21.1°C), slightly reduced turbidity, mixed gravel-bedrock substrate, and higher dissolved oxygen level (always >6.0 mg/l) provide optimal conditions for producing large numbers of hog suckers below Hoover Dam, Ohio (Cavender and Crunkilton 1974). Hog suckers apparently have been eliminated from a cold tailwater in Arkansas. They were numerous here in 1950 when the project was completed but had disappeared by 1959 (Baker 1959; Brown 1967). Reasons for the disappearance were not specified.

394. The spotted sucker is also common in some eastern tailwaters. It is one of the dominant species in Dale Hollow tailwater, Tennessee (Bauer 1976). It is also found in moderate abundance in the cold tailwaters of Hoover Reservoir, Ohio, and East Lynn Lake, West Virginia (Cavender and Crunkilton 1974; Goodno 1975). Occurrence in these tailwaters is most likely due to transport of fish over the dam from the reservoir above. Successful reproduction of spotted suckers occurs primarily in Hoover Reservoir. Young of the year escape over the dam and are found throughout the length of lower Big Walnut Creek (Cavender and Crunkilton 1974). Adult spotted suckers are the fifth most numerous species lost over the spillway of Little Grassy Lake in Illinois, composing 8 percent of total fish numbers (Louder 1958).

395. The river carpsucker occurs in both cold and warm tailwaters. It is one of the major remaining native species found below Canyon Reservoir, Texas (White 1969). It is also abundant in Lewis and Clark

tailwaters on the South Dakota-Nebraska border (Walburg 1971). The damming of Big Walnut Creek has altered quillback distribution by blocking upstream migration and increasing spring concentrations in the tailwater (Cavender and Crunkilton 1974).

396. Carpsuckers are among the most abundant fishes found below dams in the Rio Grande, New Mexico. They remain abundant in spite of the elimination of flows following the irrigation season, which reduces the river to a series of isolated pools (Huntington and Navarre 1957).

397. The food of the river carpsucker in Lewis and Clark Lake tailwater consisted primarily of zooplankton and algae (Walburg et al. 1971).

398. The white sucker has remained dominant in tailwaters below dams on many rivers where it was abundant before impoundment. The white sucker is adaptable to conditions in cold tailwaters which can closely resemble headwater stream habitats. It is abundant below Hoover Dam and is one of three dominant species in Rocky Gorge tailwater, Maryland (Tsai 1972; Cavender and Crunkilton 1974). In Twin Valley Lake tailwater, Wisconsin, the carrying capacity of the white sucker increased threefold in the 3 years following impoundment (Wirth et al. 1970). Even with a reduction of flows to only 11 percent of the historic average, white suckers have remained numerous in cold Granby tailwater in Colorado (Weber 1959). They are also abundant in the tailwater below Holyoke Dam, Massachusetts (Jefferies 1974).

399. On some rivers, the construction of reservoirs has allowed the white sucker to increase in numbers or become dominant in drainages where it was previously of only minor importance. Increased abundance of the white sucker in Dale Hollow tailwaters, Tennessee, is attributed to the deeper, more lentic habitat found in the lower tailwater, caused by the downstream impoundment of Cordell Hull Reservoir on the Cumberland River (Bauer 1976).

400. In the Taylor and Gunnison rivers in Colorado, the reduction in temperature and turbidity below some reservoirs has allowed the white sucker to outcompete most other native sucker species, e.g., flannelmouth and bluehead suckers (Mullan et al. 1976; Wiltzius 1978).

The white sucker is apparently able to reproduce in both of these reservoirs and tailwaters, which accounts for its dominance over the native suckers in the Gunnison River drainage (Wiltzius 1978). Tailwater conditions apparently aid growth, since the condition factor (weight in relation to length) of white suckers increased in Blue Mesa tailwater following impoundment (Kinnear 1967).

401. The longnose sucker has become abundant in the tailwaters of two Colorado dams, and it has also displaced the native sucker species (Mullan et al. 1976; Wiltzius 1978). The reduced temperature and turbidity in these tailwaters, together with the longnose sucker's ability to reproduce successfully, may give this species a competitive advantage.

402. Longnose suckers also adapt well to reductions in flow below dams. They have survived in flows amounting to only 11 percent of the annual average (Weber 1959). Additionally, they remain in two Wyoming tailwaters, in spite of a seasonal reduction of discharge from 24.5 to 0.04 m^3/sec and 8.8 to 0.01 m^3/sec, respectively (Wesche 1974).

403. The effects of reservoir construction and operation in western rivers on the historically dominant flannelmouth and bluehead suckers have been mixed. The flannelmouth sucker remains the most numerous native species below Glen Canyon Dam, Arizona, and the bluehead sucker is still present in Granby tailwaters (Weber 1959; Mullan et al. 1976). Numbers of flannelmouth sucker have declined in a Wyoming tailwater because of reduced water temperatures (Mullan et al. 1976). Abundance of both the flannelmouth sucker and the bluehead sucker has decreased in a New Mexico tailwater because of reduced temperatures and competition from trout (Mullan et al. 1976). However, 29 km downstream, where the river returns to its warmer, more turbid condition, the flannelmouth sucker still predominates (Graves and Haines 1968, 1969).

404. The most serious reduction of bluehead and flannelmouth suckers has occurred below two Colorado tailwaters where cold water temperatures and reduced turbidity have allowed other species to outcompete them. The result has been the disappearance of both species

from one of the tailwaters and their general decline in the other (Mullan et al. 1976; Wiltzius 1978).

405. The reduction of water temperatures in a Montana tailwater has delayed reproduction 6 to 8 weeks for both the largescale and longnose suckers. Delay in spawning has decreased the abundance of largescale suckers in this cold tailwater (May and Huston 1979). Nitrogen embolism below this site has caused some mortality of largescale suckers. Largescale suckers are extremely abundant below Dorena Dam, Fern Ridge Reservoir, Lookout Point Dam, and Dexter Dam in Oregon, apparently thriving in the 21 to 27°C temperatures commonly attained in these warmwater tailwaters (Hutchison et al. 1966).

406. The effects of reservoir operations on other less widely distributed sucker species have also been mixed. Lowered water temperatures in a Wyoming tailwater have eliminated the humpback sucker, while allowing the mountain sucker to stabilize or even increase its population (Mullan et al. 1976).

407. The blue sucker of the Missouri River is abundant in the spring and fall in the warm Lewis and Clark Lake tailwaters on the South Dakota-Nebraska border. Here it feeds heavily on zooplankton and algae and commonly eats the bryozoans and aquatic insects that are also available (Walburg et al. 1971).

Redhorse

408. Five species of redhorse are most often mentioned in literature on tailwater fish populations. They are the black, golden, silver, shorthead, and river redhorse. Generally, little factual information is available on their spawning habits, age, growth, or other life history features.

409. Habitat. The various redhorses have slightly different habitat requirements. They usually inhabit clear streams having permanent flow and clean gravelly or rocky bottoms. The black redhorse, golden redhorse, and river redhorse are most abundant in streams of medium size, whereas the shorthead redhorse and silver redhorse are most common in larger rivers. The black redhorse is more abundant than the golden redhorse in the cooler and swifter streams. Where the

two occur together, the black redhorse tends to predominate in short, rocky pools with current; whereas, the golden redhorse is most abundant in larger pools and backwaters without noticeable current.

410. The river redhorse seems less tolerant of turbidity, siltation, and intermittent flow than the other redhorse suckers. The golden redhorse is the most tolerant of both turbidity and intermittent flow, while the silver redhorse avoids spring-fed streams having high gradients and those that have excessively high turbidity. The shorthead redhorse is the most adaptable in its habitat requirements.

411. Reproduction. Redhorses spawn in April or May when water temperatures reach about 13.3°C. Spawning occurs on riffles in water 15.2 to 61 cm deep and over a bottom of small rubble mixed with lesser amounts of small gravel and sand. No nest is built; eggs are scattered over the gravel and abandoned. Spawning is completed on any given riffle within about 4 days.

412. Food. Young-of-the-year redhorse feed in backwater areas on algae and small crustaceans. Older fish shift their feeding activities to riffles, where they forage for aquatic insect larvae and other small bottom-dwelling invertebrates. The river redhorse has molarlike teeth that are an adaptation for the crushing of mollusk shells. The diet of this fish consists of mollusks, other invertebrates, and plant material.

413. Age and growth. According to Pflieger (1975), shorthead redhorse in Missouri streams reach a length of 107 mm at the end of their first year and in succeeding years lengths are 193, 264, 305, and 335 mm. The maximum life span of most redhorse is 9 or more years, except for the golden redhorse which usually does not live beyond 6 or 7 years.

414. Age and growth of the redhorses are similar except that growth of the shorthead is more rapid than that of the golden and black but slightly slower than that of the silver. The river redhorse usually grows slower than the other species during the first few years of life, but eventually it overtakes and surpasses them; it also has a longer life span.

Redhorse in tailwaters

415. The response of redhorse to tailwater conditions is similar to that of other suckers. Redhorse have increased in a number of cold tailwaters in the Tennessee Valley (Pfitzer 1962). Redhorse species were also abundant below Buckhorn Dam, Kentucky, where they numerically composed 40.8 percent of all fish present (Henley 1967). They were abundant in an Arkansas tailwater shortly after dam closure in 1950, but had disappeared by 1959 (Baker 1959; Brown et al. 1968). Cold water temperatures apparently eliminated the redhorse from this tailwater.

416. The construction of Cordell Hull Reservoir has increased water depth in the downstream portion of Dale Hollow tailwater, Tennessee. This alteration allowed the golden redhorse, a pool species, to become more abundant (Bauer 1976). In the shallower tailwaters below Hoover Reservoir, Ohio, the golden redhorse is seldom seen despite being the most abundant redhorse in the drainage (Cavender and Crunkilton 1974). Similarly, the golden redhorse is of only minor importance in terms of numbers and biomass in East Lynn Lake tailwaters in West Virginia (Jones 1975).

417. The distribution of silver redhorse in Big Walnut Creek was significantly influenced by construction of a reservoir. Although both young and adults were abundant in the reservoir headwaters prior to dam closure, they have subsequently disappeared. The presence of the dam has prevented the return of the silver redhorse to its former habitat (Cavender and Crunkilton 1974). Below Dale Hollow Reservoir, however, a population of silver redhorse has become established and has been increasing (Bauer 1976).

418. Black redhorse are common in the tailwater below Hoover Dam in Ohio. Many were observed in shallow pools below the dam in early May, which suggests that they were attempting to spawn (Cavender and Crunkilton 1974).

419. Little has been reported on the river, shorthead, and gray redhorses. The gray redhorse has survived in the cold tailwaters below Canyon Dam, Texas, and is one of the most numerous native species

remaining (White 1969). The river redhorse has increased in the lower tailwater of Dale Hollow Reservoir, Tennessee, since its inundation by Cordell Hull Reservoir (Bauer 1976). The shorthead redhorse is abundant in Lewis and Clark Lake tailwater, South Dakota and Nebraska. Here it feeds primarily on zooplankton from the reservoir discharge, but algae, bryozoans, and aquatic insects are also commonly eaten (Walburg et al. 1971).

Ictaluridae (Catfishes)

420. The catfish family includes 37 species, all generally restricted to North and South America. In the United States, they occur naturally in larger rivers, lakes, and slow-moving waters east of the Continental Divide. Some of the larger species have been widely introduced outside their natural range and now occur throughout the United States. Species commonly found in tailwaters are the channel catfish, flathead catfish, and, to a lesser extent, bullheads; the blue catfish and the white catfish are important regionally. All are popular food and game fishes. Lesser known species which also occur in tailwaters are collectively referred to as "madtoms." They are rarely seen because of their small size and secretive habits. This discussion of ictalurids includes the three general groups--bullheads, catfishes, and madtoms.

Bullheads

421. Habitat. The black, brown, and yellow bullheads may occur in tailwaters, but they are essentially quiet-water fishes found in lakes, ponds, or sluggish streams. They occur in a variety of habitats but are most abundant in areas with turbid water, a silt bottom, and no noticeable current or strong flow. Especially favorable habitats are the permanent pools of small intermittent creeks and muddy oxbows and backwaters of large streams. Black bullheads usually inhabit the lower sections of small- to medium-sized streams of low gradient, ponds, backwaters of larger rivers, and silty, soft-bottomed areas of lakes and impoundments. They do not inhabit the areas in which brown

and yellow bullheads usually occur but seem to replace them if the habitat deteriorates. Yellow bullheads seem to prefer clearer water.

402. Reproduction. The reproductive habits of the bullheads are similar. They spawn in late spring or early summer, when water temperatures reach about 21°C, in saucer-shaped nests fanned out by one or both parent fish. Nests are usually beneath some type of cover such as logs or objects elevated above the stream bottom. One of the parents remains continuously with the eggs until they hatch. Minnows and sunfish are often observed near the nest, rushing in to eat eggs whenever the opportunity arises. Eggs hatch in 6 to 9 days at 20.6 to 23.3°C. At hatching, the young are about 6 mm long; they remain in the nest until about the seventh day. The young bullheads move about in a compact school after leaving the nest, and continue to be accompanied by one or both adults. The young are abandoned by the adults when about 25 mm long but persist in schooling throughout the first summer of life.

403. Food. Bullheads are truly omnivorous and feed primarily from the bottom on a variety of plant and animal material. Adults eat immature aquatic insects, clams, snails, crustaceans, plant material, leeches, and fish. Young up to 25 mm long feed almost exclusively on small crustaceans. Older young feed on chironomid larvae, cladocerans, ostracods, amphipods, and mayflies.

404. Age and growth. In Oklahoma waters, the black bullhead averages 94 mm in length by the end of its first year of life and is about 170, 229, 274, 312, and 350 mm long at the end of succeeding years (Houser and Collins 1962). Growth in various habitats is highly variable, however, being slowest in overpopulated ponds and streams and fastest in new impoundments. Bullheads may grow to 250 mm during the first year of life in new reservoirs, but may not reach this length until the fifth or sixth year in an overpopulated stream. Maximum life span is about 10 years, but few individuals live more than 5. Yellow and brown bullheads attain slightly larger size than the black bullhead.

Bullheads in tailwaters

425. Bullheads may occur in tailwaters, but this habitat is generally unsuitable because of reduced turbidity and strong currents. Bullheads found in tailwaters are often produced in backwaters or in the upstream reservoir and carried through the dam into the tailwater.

426. In some warm tailwaters, bullheads coming from the reservoir above are an important part of the fishery. A 1959 preimpoundment rotenone survey of Barren River, Kentucky, estimated bullheads to be 0.6 percent of the river fish community; few were taken by anglers (Carter 1969). In a 1968 creel survey at the Barren tailwater, it was estimated that 33.8 percent of the anglers' catch was bullheads. Fishing success in the tailwater during 1968 was correlated with dam discharge; fishing was good when discharge was high and poor when it was low (Charles and McLemore 1973). Good fishing success for bullheads during periods of high flow and low historical bullhead populations in the river, indicate that the bullheads were probably produced in the reservoir and transported through the dam into the tailwater. The creel census in the Barren tailwater from 1968 through 1971 showed a steady decline in the bullhead catch from 34.8 to 0.3 percent of the total harvest (Charles and McLemore 1973). This decline not only indicates that the bullhead population was unable to reproduce in the tailwater environment, but also reveals a lack of further recruitment into the tailwater from the reservoir above.

427. Below Carlyle Dam, Illinois, bullheads made up 6.2 percent of the 1968 catch by anglers. The bullhead harvest was 0.38 fish/hour in the reservoir compared with 0.08 fish/hour in the tailwater (Fritz 1969). These figures indicate a greater abundance of bullheads in the reservoir. Apparently bullheads favor the reservoir habitat over the flowing tailwater. Bullheads from Fern Ridge Reservoir, Oregon, have established a fishery in the warm tailwater (Hutchison et al. 1966). Hall and Latta (1951) found that 8 percent of the fish in the stilling basin below Wister Dam, Oklahoma, were black bullheads. They believed that the fish found in the warm tailwater, including the bullheads, reflected the species composition of the reservoir above and not the

river downstream. The black bullhead is abundant in the Stillwater Creek drainage in Oklahoma, but occurs infrequently in the Lake Carl Blackwell tailwater. This is most likely due to the strong currents in tailwaters, which do not provide suitable bullhead habitat (Cross 1950).

428. Bullheads are found in tailwaters with wide temperature ranges and low dissolved oxygen concentrations. Electrofishing showed that black bullheads were the most abundant fish and ranked third in biomass in East Lynn tailwater, West Virginia, where water temperatures ranged from 5 to 25°C and averaged 16.6°C (Goodno 1975). Pierce (1969) stated that bullheads became more abundant after construction of Summersville Dam, West Virginia, even though tailwater temperatures did not exceed 15.6°C. Summers (1954) captured bullheads by trap net below Tenkiller Dam, Oklahoma, in water of 12.2 to 17.8°C, swift currents, and dissolved oxygen concentrations of less than 0.5 mg/l. Possible increased production of bullheads in these reservoirs and their export into the tailwaters may account for the large numbers of bullheads observed.

429. Only two papers reported food habits of bullheads in tailwaters. Olson (1965) stated that bullheads in Navajo tailwater, New Mexico, ate a diet similar to that of rainbow trout, consisting of dipterans, plecopterans, ephemeropterans, algae, and fish; only gastropods (eaten by trout) were excluded from the bullhead diet. Brown bullheads below Holyoke Dam, Massachusetts, ate (by volume) 37.4 percent detritus, 35.3 percent algae, 11.8 percent pelecypods, 11 percent fish, 2.2 percent bryozoans, and 2.4 percent other items (Jefferies 1974).

Catfish

430. Habitat. Four catfish species have been collected from tailwaters: channel catfish, flathead catfish, blue catfish, and white catfish. The last two species resemble the channel catfish and are regional in distribution. The white catfish is found in Atlantic coastal streams from New Jersey south to Florida, and the blue catfish occurs only in the Missouri and Mississippi rivers and their principal

tributaries. This discussion concerns only the channel catfish. The flathead catfish may occur in tailwaters, but is little mentioned in tailwater literature.

431. The channel catfish is found in a variety of habitats but is most common in large streams having low or moderate gradients. Though channel catfish prefer currents, excessive current or insufficient water depth limits their distribution. Adults are usually found in deep-water pools or near submerged logs and other cover. The young are commonly found in riffles or the shallower parts of pools. Adults are most active at night, when they move into shallow water to feed.

432. Reproduction. The channel catfish spawns in late spring or summer when water temperatures are between 24.0 and 29.4°C. Catfish spawn in nests selected by the male. Nest sites are natural cavities under submerged logs or debris, animal burrows, or undercut stream banks. The eggs hatch in about a week and the fry remain in the nest for 7 or 8 more days. The male guards the nest until the fry leave. Because of predation, the survival of catfish during their first summer of life is usually greater in turbid than in clear ponds or streams.

433. Food. Channel catfish feed mostly on the bottom and locate food primarily by taste. Bailey and Harrison (1948), who conducted studies on the food habits of channel catfish in the Des Moines River, Iowa, found that fish less than 100 mm long fed almost entirely on small insects. Larger catfish had a more varied diet, including fish, insects, crayfish, mollusks, and plant material.

434. Age and growth. In the Salt River in Missouri, the channel catfish averages 65 mm in length at the end of its first year of life and is about 135, 206, 259, 297, 340, and 399 mm long at the end of succeeding years (Purkett 1958a). Studies by Barnickol and Starrett (1951) in the Missouri-Illinois section of the Mississippi River showed that channel catfish mature when 4 or 5 years old at a length of 305 to 381 mm. Adults were commonly 305 to 815 mm long and weighed 0.4 to 6.8 kg. Life span is apparently dependent on growth rate. Slow-growing fish in Canada may live longer than 20 years; whereas, fast-growing fish from the southern United States may not live longer than 6 or 7 years.

Catfish in tailwaters

435. Channel catfish are important game fish in some tailwaters, particularly in the southeastern United States. Changes in stream habitat caused by dam construction have had varied effects on channel catfish. They are often abundant in the warm tailwaters of turbid main-stem or tributary rivers but are uncommon or absent in clear, cold tailwaters.

436. Channel catfish disappeared from the angler catch in a Missouri reservoir because of coldwater discharge (4.4-15.6°C) from an upstream reservoir (Hanson 1969). Below an Arizona dam, channel catfish were second in importance to rainbow trout until the water cooled from 14.8°C in 1967 to 10.4°C in 1971 and 1972. The cooling trend caused channel catfish to leave the tailwater (Mullan et al. 1976).

437. Channel catfish abundance below a Kentucky reservoir apparently decreased after dam construction (Carter 1969). Water is released from the hypolimnion to maintain a tailwater trout fishery. Channel catfish composed 35.4 percent of the anglers' catch in the tailwater area before impoundment in 1959, but never more than 2 percent after impoundment (Carter 1969; Charles and McLemore 1973). The change from hypolimnetic releases in 1968 and 1969 to epilimnetic releases in 1970 and 1971 did not noticeably affect the channel catfish catch. Both release regimes resulted in water temperatures below those of the historical monthly average for the Barren River (Carter 1969).

438. Downstream from a cold tailwater, as local conditions moderate the dam discharge, catfish populations may increase. Graves and Haines (1969) stated that channel catfish were the main game fish 29.0 km below a New Mexico dam where turbidity and water temperature had increased. Further upstream in the tailwater, trout predominated.

439. Turbid main-stem tailwaters and tributary warmwater tailwaters often concentrate catfish and create a fishery. Cross (1950) believed that channel catfish below Lake Carl Blackwell, Oklahoma, had escaped from the reservoir and remained in the tailwater because food was abundant and flows were stabilized. In June and July, an

upstream migration of channel catfish in Stillwater Creek resulted in a large concentration in the Blackwell tailwater. Channel catfish were also most abundant in Lewis and Clark tailwater, South Dakota, during the summer (Walburg 1971). Channel catfish concentrate and provide a fishery below Lock and Dam Number 12 on the Mississippi River in Iowa (Gengerke 1978). This species is second in biomass and fifth in abundance in East Lynn Lake tailwater, West Virginia (Goodno 1975). A comparison of the fish population in the stilling basin area before and after closure of the warmwater Wister Dam, Oklahoma, showed a reduction in the channel catfish population from 34 percent of the total numbers of fish to 11 percent (Hall and Latta 1951). The reduction reflected the change of a community associated with a river to one more commonly associated with a reservoir.

440. Little information is available on the food and growth of channel catfish found in tailwaters. In Lewis and Clark tailwater, they ate fish, crayfish, and aquatic insects. In April and May, when Hexagenia was abundant in the tailwater, it was a major food item, but as abundance of Hexagenia declined in the summer, catfish ate more fish (Walburg 1971). Catfish in Dale Hollow tailwater, Tennessee, ate primarily dipterans (Little 1967). Channel catfish grew faster in Lewis and Clark Lake than in the tailwater (Walburg 1971).

Madtoms

441. Habitat. Madtoms inhabit clear to moderately turbid streams having permanent flow and low or moderate gradients. Some species are also found in the shallows of lakes and their outlets. They generally occur on riffles over a gravelly or rocky bottom. Some species may also be found over sandy bottoms in areas with fast current, and others, such as the brindled madtom, in pools below riffles associated with organic debris such as roots, leaves, twigs, and logs. Species vary in their tolerance of current and turbidity. Madtoms are most active at night, often hiding by day beneath large rocks or other cover.

442. Reproduction. Madtoms spawn from late spring into the summer. Peak spawning occurs when water temperatures reach 25.6 to 27.8°C.

Eggs are deposited as a compact cluster in a shallow depression excavated beneath a flat rock or other forms of protection such as tin cans, boards, or crockery. Nests are guarded by one of the parent fish. Newly hatched young are about 10 mm long.

443. Food. Madtoms are active at night, foraging over riffles and shallow pools. They feed primarily on insect larvae and small crustaceans that live on the bottom. Occasional small fish are also eaten.

444. Age and growth. Little information is available on growth of madtoms. Carlson (1966), who studied the stonecat in the Vermillion River in South Dakota, found that they averaged 79 mm at the end of the first year of life and 99, 114, and 137 mm by the end of succeeding years. The largest specimen was 193 mm long and in its seventh year.

445. Other species of madtom are smaller than the stonecat and their total length at the end of their first year ranges from 36 to 64 mm. Adults of most species are 51 to 102 mm long and maximum length is about 127 mm. Many mature in their second summer and few live longer than 3 years.

Madtoms in tailwaters

446. There are few reports on madtoms in tailwaters. Carter (1969) found the brindled madtom in the Barren tailwater, Kentucky, in 1964 and 1965. Four species of madtoms--the slender, brindled, freckled, and an undescribed species--were collected in the Barren River during a preimpoundment survey in 1959. In the Owyhee River, Oregon, tadpole madtoms were commonly found in both the tailwater below Owyhee Dam and in the reservoir above (Fortune and Thompson 1969). Stonecats were collected below four impoundments on the Au Sable River, Michigan, in the 1920's, but none were collected in a 1972 survey (Richards 1976).

Percichthyidae (Temperate Basses)

447. These basses include several freshwater and marine genera. The white bass and the less common yellow bass both occur naturally

in the Mississippi River drainage. The striped bass was introduced into many reservoirs during the past 20 years from anadromous stocks native to coastal rivers and estuaries in Virginia, North Carolina, and South Carolina. These plantings have been successful in some states, and striped bass are now relatively common in some river-reservoir systems. Examples of states with successful striped bass fisheries in both reservoirs and tailwaters are Oklahoma and Tennessee. Reproduction of introduced striped bass has been limited, and the maintenance of fishable stocks is often dependent on annual plantings of hatchery-produced fish. The life history discussion of temperate basses is limited to the white bass; the tailwater discussion includes both white bass and striped bass.

White bass

448. Habitat. White bass inhabit the deeper pools of streams and the open waters of lakes and reservoirs. During the spring spawning migrations, large numbers enter tributary streams and are the basis for an important seasonal fishery. The white bass tends to avoid waters that are continuously turbid and is most often found over a firm sand, gravel, or rocky bottom. It has been introduced into many lakes and reservoirs throughout the United States.

449. Reproduction. The white bass spawns in early spring and spawning is usually preceded by the migration of mature adults into tributary streams. The prespawning schools are composed of only one sex. Males move onto the spawning grounds about a month before the females. The spawning period throughout their range is from April through June, when water temperature is about 15.6°C. Spawning occurs in midwater or near the surface, over a gravelly or rocky bottom, often in a current, and without preparation of a nest. Spawning is generally completed at any given locality over a period of 5 to 10 days; there is no parental care of eggs or young. The eggs settle to the bottom, where they hatch in about 2 days. Newly hatched larvae are about 3 mm long.

450. Food. White bass usually feed in schools, appearing in large numbers where food is abundant and moving on when the supply is

exhausted. Most feed near the water surface in early morning and late evening, where they pursue forage fish, small crustaceans, and the emerging stages of aquatic insects. Zooplankton and aquatic insects are the most important diet items for young white bass. The diet of adults is largely composed of fish; however, zooplankton and insects are also important.

451. Age and growth. Growth of the white bass is rapid; the life span is seldom more than 4 years in southern waters, but may be 7 or 8 years in northern waters. In Lake Wappapello, Missouri, this fish reached a length of about 185 mm its first year and averaged 302, 338, and 358 mm by the end of succeeding years (Patriarche 1953). Few white bass attain a length and weight of more than 445 mm and 1.2 kg.

Temperate basses in tailwaters

452. The white bass is an important sport fish in many tailwaters, especially during the spring. In the warm tailwaters of Clearwater Lake, Missouri, it made up 3.9 percent of the anglers' catch in 1961 and 14.1 percent in 1964 (Fry 1965; Hanson 1965). It composed 8 percent of the anglers' catch below Pomme de Terre Reservoir, Missouri, during 1965-74 (Hanson 1977).

453. In the Tennessee Valley, white bass support important spring fisheries in cold tailwaters, which are primarily the result of spring migrations upstream from reservoirs (Pfitzer 1962). The fish is a particularly important game species below the main-stem reservoirs; for example, in Watts Bar tailwater it composed 18.8 percent of the anglers' catch in 1953 (Miller and Chance 1954). Large numbers of white bass have also been observed migrating upstream out of Watts Bar Reservoir into Norris Dam tailwater (Eschmeyer and Manges 1945).

454. In Dale Hollow tailwater, Tennessee, white bass became abundant in the lower tailwater after the filling of Cordell Hull Reservoir (Bauer 1976). White bass are also important in the fishery below Tenkiller Dam, Oklahoma, where they composed 8 percent of the catch immediately below the dam and 43 percent at a point 12.8 km downstream (Deppert 1978).

455. Lake Taneycomo tailwater, Missouri, is influenced by the presence of Table Rock Reservoir upstream and Bull Shoals Reservoir downstream. Increased power production at the deep-release Table Rock Dam has converted Lake Taneycomo tailwater from a warmwater to a coldwater tailwater, making conditions unfavorable for warmwater game fish. The magnitude of spring migration of white bass into Lake Taneycomo tailwater from Bull Shoals Reservoir, however, is most heavily influenced by the level of Bull Shoals Reservoir, which inundates Lake Taneycomo tailwater. Maximum spring migration of white bass into the tailwater occurred when Bull Shoals Reservoir was between 0.6 and 3.0 m below power pool. Above or below these levels the migration rate declined proportionately (Fry 1965; Hanson 1969).

456. The food and reproductive habits of white bass in tailwaters are not well known. Of 165 stomachs of immature white bass collected from Norris tailwater, Tennessee, in the winter of 1942-43, 140 were empty (Eschmeyer 1944). White bass in Lewis and Clark tailwaters, South Dakota, fed on zooplankton in the spring and fall, and predominantly fish in summer (Walburg et al. 1971). Little reproductive success was noted in either of these tailwaters (Eschmeyer and Manges 1945; Walburg et al. 1971).

457. Striped bass have been stocked in a number of reservoirs and tailwaters in an effort to control large gizzard shad populations and to enhance the sport fishery; however, they have been found to compete with trout in tailwaters. Below Davis Dam, Arizona, 24 trout 200 to 230 mm long were found in 20 striped bass stomachs examined (Arizona Game and Fish Department 1972). Additionally, food studies on striped bass in Tenkiller tailwater, Oklahoma, showed that rainbow trout composed 40 percent by number of the food items eaten by striped bass during the first week after the trout were stocked. Gizzard shad was the primary striped bass food in this tailwater, accounting for 56 percent of the total number of food items during the first week after trout stocking and 75 percent at other times (Deppert 1978). Similar results were noted in Keystone Dam tailwaters, Oklahoma, where gizzard shad made up 95 percent of the food eaten (Combs 1979).

Centrarchidae (Sunfishes)

458. Fishes of this family are found in nearly all types of waters, and most are highly sought by sport fishermen. Their habits and life history are similar, differing only in detail. Centrarchids migrate little; most remain in the same stretch of stream or shoreline throughout life. Feeding is by sight, and feeding activity peaks in early morning and late evening, accompanied by movement into shallow water. All centrarchids construct nests for spawning, but only males participate in this activity. They guard the eggs after they are deposited and remain until fry leave the nest. The centrarchids are discussed under three general groups--black basses, "true sunfishes," and crappies.

Black basses

459. Three black bass species are commonly found in tailwaters--the smallmouth bass, spotted or Kentucky bass, and largemouth bass.

460. Habitat. Smallmouth bass prefer clear, cool, permanent-flowing streams with good gradient (1.[illegible] to [illegible].8 m/km). Preferred summer water temperature is about 21°C. The fish generally occur over a silt-free rock or gravel bottom, near riffles, but not in the main current. Adults are most abundant near cover in the form of boulders, roots, or sunken trees. In large rivers with navigation dams, they are usually restricted to the rocky shoals below dams, where streamlike conditions still prevail. The smallmouth normally limits it's activities to a single stream pool, but occasionally its home range includes several pools as much as 0.8 km apart.

461. Spotted bass inhabit flowing waters that are warmer and slightly more turbid than those favored by smallmouth bass. Preferred summer temperature is about 24°C. The habits of the spotted bass are similar to those of the smallmouth, except that the spotted bass is more migratory.

462. The largemouth bass is more widely distributed than the other basses and is the most abundant bass species in standing-water habitats. Its preferred summer temperature is about 27°C. It is

commonly found in lowland lakes, reservoirs, slow-flowing streams, and backwaters of large rivers. It is intolerant of excessive turbidity, and in streams with continuous strong flow it is replaced by one of the other basses. The largemouth displays more seasonal movement than either the smallmouth or spotted bass.

463. Reproduction. The smallmouth bass begins nesting in the spring when the water temperature exceeds 15.6°C. Nesting activity usually peaks in late spring, but sometimes continues well into early summer. Renesting occurs if early nests are unsuccessful because of high water or low temperatures, and may occur even if the first nests are successful. Nests are in quiet water near shore or downstream from a boulder or other obstruction that breaks the force of the current. Water depth rarely exceeds 1 m over the nest. Smallmouth bass eggs are golden yellow and about 2.5 mm in diameter. They are distinguished from those of the spotted bass and largemouth bass by their larger size. Eggs hatch in 2 or 3 days and fry remain on the gravel for about 6 days before leaving the nest.

464. Spotted bass generally begin spawning several days later than smallmouth bass in the same stream. Nests are similar to those of the smallmouth bass, and the development of eggs and fry is similar at the same temperature. Fry of the spotted bass disperse from the nest 8 or 9 days after spawning if the water temperature is above 20°C.

465. The largemouth bass begins spawning in the spring when water temperature reaches about 15.6°C and continues into late spring. Nests are constructed on almost any type of firm, silt-free bottom. Water depth over nests may vary from 0.3 m or less to 4.6 m or more, being deepest in the clear waters of large impoundments. Nests are never constructed where there is current or wave action. In streams, nests are located in the deeper and quieter parts of pools or in adjacent sloughs. Eggs are about the size of spotted bass eggs and are much smaller than those of the smallmouth. They hatch in 3 or 4 days and fry leave the nest as a school when about 10 days old. Schools break up 26 to 31 days after hatching, when the young bass are slightly over 25 mm long. The male largemouth is a more attentive parent than any of

the other sunfishes, remaining with the schooling young for several weeks after they leave the nest.

366. <u>Food.</u> Midge larvae and zooplankton are the first foods of smallmouth bass fry. According to Pflieger (1975), fry less than 25 mm long eat small fish, and fish remain an important part of their diet throughout life. Crayfish and fish occur in about equal amounts in the diet of adult bass. Insects are taken frequently but are of only minor importance.

367. Immature stages of aquatic insects are the principal diet of spotted bass of all sizes. Insects are supplemented with small crustaceans in bass less than 75 mm long, and with crayfish and fish in larger bass (Smith and Page 1969).

368. The first food of young largemouth bass consists mostly of zooplankters, but these are supplemented by insects and their larvae as the young bass increase in size (Pflieger 1975). Adults feed principally on fish, crayfish, and large insects, along with an occasional frog, mouse, or almost any other animal that swims or falls into the water. In large reservoirs, the largemouth bass depends heavily on gizzard shad as food, and there is a definite relation between the trends in abundance of the largemouth and those of its principal prey species.

369. <u>Age and growth.</u> In Missouri streams, the smallmouth bass averages 90 mm long when 1 year old, and attains lengths of about 170, [illegible], 290, [illegible], and 271 mm in succeeding years (Purkett 1958b). As is common in fishes, growth is more rapid in larger streams than in headwater creeks. A Missouri smallmouth bass weighs about [illegible] g at a length of [illegible] mm, and about [illegible] g at 356 mm. Smallmouth bass seldom exceed a length of [illegible] mm or a weight of 2.5 kg. Missouri smallmouth bass become mature during their third or fourth summer of life and some live 10 or [illegible] years.

370. Growth of spotted bass is slightly faster than that of the smallmouth for the first 4 years of life but is slower thereafter. In Missouri streams, lengths attained are about [illegible] mm the first year and about [illegible], [illegible], [illegible], [illegible], and [illegible] mm in succeeding years (Purkett

1958a). Growth appears to be more rapid in reservoirs than in streams. Most fish are mature when 3 or 4 years old. Few spotted bass live longer than 6 years or attain a weight much greater than 1.4 kg.

471. Growth of the largemouth bass is extremely variable, depending on local conditions. In Lake Wappapello, Missouri, a length of about 135 mm is attained the first year and lengths of 277, 338, 409, 460, and 498 mm are reached in succeeding years (Patriarche 1953). Growth rates are similar or faster in new, well-managed ponds, but much slower in highly turbid or overpopulated ponds, which may contain bass 4 years old or older that are still less than 254 mm long. Fish mature between the ages of II and IV, depending on growth rate. Under average conditions a 305-mm bass weighs about 340 g and a 560-mm bass about 2.7 kg. Individuals weighing more than 4.6 kg are not uncommon. Few largemouth bass live beyond 12 years.

Black basses in tailwaters

472. Black basses are important game fish in rivers and reservoirs in many areas of the United States. They occur in tailwaters if water temperatures are suitable and cover is adequate. Black bass populations have been reduced below many hypolimnetic release dams constructed on warmwater streams because of low water temperatures, strong currents, and lack of instream cover.

473. The smallmouth bass fishery below Hoover Dam, Ohio, was lost due to hypolimnetic water discharge from the dam (Cavender and Crunkilton 1974). Pierce (1969) showed a reduction in smallmouth populations from 7.24 to 4.72 kg/ha in the Summersville tailwater, West Virginia, based on preimpoundment and postimpoundment electrofishing studies. The maximum temperature in Summersville tailwater is 15.6°C, which is below the optimal range for smallmouth bass. Dendy and Stroud (1949) believed that low water temperatures and low dissolved oxygen following construction of Fontana Dam, North Carolina, adversely affected smallmouth bass for many miles downstream in the Little Tennessee River. The coldwater discharge from Table Rock Reservoir, Missouri, caused the loss of smallmouth and spotted bass downstream in Lake Taneycomo (Fry and Hanson 1968).

474. Cold tailwaters below two dams in Kentucky support fewer black basses than occurred in the natural river before impoundment. Black basses were estimated to be 47.9 and 19.1 percent of the angler catch in a 1959 creel survey from these two rivers (J. P. Carter 1968a). In 1968-71, after dam construction, black basses composed only 0.1 to 2.6 percent of the angler catch (Charles and McLemore 1973). Apparently the tailwater habitat differed from the original warmwater stream habitat and did not provide the conditions necessary to sustain the bass fishery.

475. Smallmouth bass were common in angler catches in the tailwater below Cherokee Dam, Tennessee, for the first 8 years after impoundment. The fishery changed thereafter, and anglers had to fish 32 to 40 km downstream to catch smallmouth bass (Pfitzer 1962). Low water temperatures apparently reduced bass reproduction and numbers in the upper 32 km of the tailwater.

476. Eschmeyer and Manges (1945) showed that the condition factor of largemouth bass declined from autumn 1942 to autumn 1943 in a Tennessee tailwater. They believed the fish were experiencing high natural mortality due to the harsh habitat in this cold tailwater.

477. Some warm and cool tailwaters sustain black bass populations when water temperatures and cover are adequate. Many young-of-the-year smallmouth bass were captured by seine below a low-head dam on the Maquoketa River, Iowa. The large concentrations of fish in this tailwater were believed to be a result of high oxygen levels, blockage of upstream movement, and habitat diversity (Paragamian 1979). Hutchison et al. (1966) found low to moderate smallmouth bass abundance below Cottage Grove Dam and Dorena Dam, Oregon. These flood control dams have caused an increase in water temperature in the tailwaters and have made them more suitable for smallmouth bass and less suitable for trout and salmon. Andrews et al. (1974) compared the catch of largemouth bass in the river above and below an Oklahoma reservoir. Historically, largemouth bass were abundant in the deep pools of the downstream section where flows were more stable. After impoundment, 90 percent of the largemouth bass were caught in the river above the

reservoir, and they provided 35 percent of the estimated catch of all fish species. Coolwater discharge and fluctuating flows below this main-stem hydropower dam apparently reduced habitat suitability for largemouth bass in the tailwater.

478. Food of largemouth and smallmouth bass from Holyoke Dam tailwater, Massachusetts, was studied in 1972 (Jefferies 1974). The frequency of occurrence of fish, insects, and crayfish in largemouth bass stomachs was 88.9, 16.7, and 7.8 percent. Fish (spottail shiners) made up 93.4 percent and crayfish 5.3 percent of total food volume. The largemouth bass selected spottail shiners over Alosa spp. Smallmouth bass stomachs contained fish, insects, crustaceans, and pelecypods. Fish made up 45 percent of the stomach contents, crustaceans 35 percent, and pelecypods 20 percent. In largemouth bass collected below Norris Dam, Tennessee, 42 of 53 stomachs examined were empty. Apparently the cold tailwater did not provide good bass habitat since the fish exhibited no growth (Eschmeyer 1944, Eschmeyer and Manges 1945).

479. Reproduction of black basses in tailwaters is not well documented. There is no documented reproduction of smallmouth bass in South Holston tailwater, Tennessee. No juvenile bass were captured in this tailwater and many adult females from a November 1953 collection had resorbed their eggs (Pfitzer 1962). Young-of-the-year largemouth bass were the most abundant centrarchid in collections taken in 1965 below Beaver Dam, Arkansas. However, it is not known whether these fish were produced in the tailwater or had moved out of the reservoir above. In 1966, no largemouth bass adults or juveniles were captured in the tailwater (Brown 1967).

480. Generally, cold tailwaters do not provide good bass habitat. Limited bass fisheries have developed below some dams, but fish harvest usually remains low. Successful bass fisheries are usually found in warm tailwaters with backwaters or other sheltered areas.

True sunfishes

481. The most common of the "true sunfishes" (a term applied here to the Lepomis sp. of the family Centrarchidae) occurring in tailwaters

are the bluegill, green sunfish, and longear sunfish. Also included in this section is the rock bass. Other true sunfishes may be locally abundant in tailwaters, but their life histories are generally similar to those described.

482. Habitat. The bluegill is common in the deeper pools and backwaters of streams, and in lakes, ponds, and reservoirs. It is intolerant of continuous high turbidity and siltation and thrives best in warm, quiet-water areas with some aquatic vegetation.

483. The green sunfish tolerates a wide range of conditions, but does best where few other sunfishes occur. It is adaptable for survival in fluctuating environments, since it tolerates extremes of turbidity, dissolved oxygen, temperature, and flow.

484. The longear sunfish is characteristic of clear streams with sandy or rocky bottoms and permanent flow. It is more common in streams than in large rivers. Like other sunfishes, it avoids strong currents and is usually found in pools and backwaters adjacent to the stream channel. In most environments, when longear sunfish are common, green sunfish are few.

485. The rock bass commonly occurs in streams. Permanent flow, low turbidity, abundant cover, and silt-free bottoms are its basic requirements. It is usually found near boulders, submerged logs, and tree roots where there is a slight to moderate current. A deep rocky pool immediately below a riffle is a favored spot.

486. Reproduction. The true sunfishes appear to have similar spawning habits. Fish begin nesting in the spring when water temperatures are about 21°C. Spawning reaches a peak in June but often continues into August. Nesting occurs on almost any type of bottom, but gravel is preferred. Nests are usually in water 0.3 to 0.6 m deep and consist of roundish depressions with a diameter about twice the length of the male parent. Many nests are commonly close together and in a limited area. The green sunfish is less colonial than some of the other sunfishes in its nesting habits. The male guards the nest until the eggs hatch but does not guard the fry once they leave the nest.

Because of their similar spawning habits, the various sunfish species often crossmate and produce hybrids.

487. The nesting season of the rock bass coincides with that of the smallmouth bass and precedes that of the sunfishes. Nests have been observed as early as the first week of April and as late as early June in Missouri, but in any given year the season seldom lasts more than one month (Pflieger 1975). Nesting begins when stream temperatures range between 12.8 and 15.6°C. The male rock bass fans out a saucer-shaped depression 200 to 250 mm in diameter over a bottom of coarse sand or gravel. Nests are in water from 0.3 to 1.5 m deep, usually near a boulder or other large object, and often where there is a slight current. The rock bass is a solitary nester, in contrast to the true sunfishes, which tend to nest in colonies.

488. Food. The diets of true sunfishes and rock bass are generally similar. Young of the year feed on zooplankton and immature aquatic insects, and older fish on aquatic insects, supplemented with small fish, crayfish, and snails. Feeding is most intense during the early morning and in the evening.

489. Age and growth. Growth of the bluegill varies considerably from one body of water to another. Growth is usually slower in streams than in ponds, lakes, or reservoirs. In most Missouri waters, the bluegill reaches a length of 150 mm and a weight of about 70 g by the end of its third or fourth summer of life. A 215-mm bluegill weighs about 225 g. Bluegills commonly reach a length of 240 mm and a weight of 340 g (Pflieger 1975).

490. The green sunfish attains lengths of about 43, 81, 119, 150, and 193 mm at an age of 1 through 5 years, in the Salt River, Missouri (Purkett 1958a). A 150-mm green sunfish weighs about 85 g; few individuals exceed a length of 230 mm or a weight of 340 g.

491. In Missouri streams, the longear sunfish attains a length of about 33 mm its first year and 64, 91, 109, 122, and 127 mm in succeeding years (Purkett 1958b). The maximum length and weight are about 175 mm and 128 g.

492. Rock bass from Ozark streams in Missouri average 41 mm in length by the end of their first year of life and attain lengths of 86, 140, 178, 203, and 216 mm in succeeding years (Purkett 1958a). Few live more than 5 or 6 years, but they commonly attain a length and weight of up to 280 mm and 454 g.

493. In summary, growth of the true sunfishes varies considerably from one water body to the next, and stunting occurs in crowded populations or where water is continuously turbid. Generally the bluegill, rock bass, and green sunfish attain the largest size.

True sunfishes in tailwaters

494. The abundance of sunfishes in tailwaters is variable and depends on recruitment and the available habitat. The occurrence of sunfishes in tailwaters below Tennessee Valley Authority storage reservoirs was found to depend on fish present in the river before impoundment, fish entering the tailwater from the reservoir above, and migration into the tailwater from tributary streams or reservoirs downstream (Pfitzer 1962). Cavender and Crunkilton (1974) reported bluegills and white crappies being carried over the spillway of Hoover Dam, Ohio, and establishing small populations in the tailwater. Bluegills were also periodically transported over spillways into the tailwaters of Urieville Lake and Wye Lake, Maryland, and Loramie Lake, Ohio (Clark 1942; Elser 1960).

495. Sunfishes generally prefer areas with instream cover, low currents, and maximum water temperatures above 21°C. Sunfish populations are usually depressed in tailwaters that are cold, or have high turbidity or little instream cover. Bluegills, longear sunfish, and green sunfish were collected in Norfork tailwater, Arkansas, in 1950 (reservoir impounded in 1944), but were lacking in collections made in 1959 (Hoffman and Kilambi 1970). Brown (1967) found several sunfishes in the same drainage below the newer Beaver Dam in 1965 (reservoir impounded in 1961). Apparently several years are required before the reduction in temperature eliminates sunfishes from these cold tailwaters. Table Rock tailwater (Lake Taneycomo), Missouri, was converted from a warm to a cold tailwater when hypolimnetic discharges

were begun in 1959. Bluegills were the only warmwater species to remain abundant after the change to cold water. Most of the bluegills were captured at the downstream end of Lake Taneycomo, where solar warming and some thermal stratification occurred (Fry and Hanson 1968). Bluegills and longear sunfish composed over 50 percent of the total numbers of fish collected by electrofishing in Nolin tailwater, Kentucky, in 1965 and 1966. The abundance of sunfishes in the tailwater was due primarily to export of fish from the reservoir above (J. P. Carter 1968b). A change from epilimnetic to hypolimnetic release and the stocking of trout in the tailwater in 1970 and 1971 resulted in a reduction of the sunfish harvest. The sunfish catch from 1968 to 1971 declined from 79.4 to 10.7 percent of the total number of fish caught and from 44.6 to 3.4 percent of the total fish weight (Charles and McLemore 1973). Reports of sunfishes in other cold tailwaters are limited. Bluegills, green sunfish, and redear sunfish composed only 5 percent of the 1975 fish community in Dale Hollow tailwater, Tennessee (Bauer 1976).

496. Studies on several warm tailwaters suggested that sunfishes can be important in the fishery. Bluegills were estimated to be 8, 12, and 13 percent of the angler catch at Lake of the Ozarks, Pomme de Terre, and Stockton tailwaters, Missouri. Both Lake of the Ozarks and Pomme de Terre have epilimnetic discharges, resulting in maximum water temperatures of about 29°C (Hanson 1974). A highly significant correlation between total annual discharge and annual average catch rate was found at Pomme de Terre. Hanson's findings agreed with the conclusions of Moser and Hicks (1970) that tailwater fisheries are supported by fish from the reservoir (Hanson 1977). Carter (1969) stated that sunfishes in the Barren tailwater, Kentucky, were more abundant when water was released from the epilimnion rather than from the hypolimnion. The warm water, in combination with the abundant instream cover, accounts for the increase of sunfishes. Of the fish seined below Lake Carl Blackwell, Oklahoma, 15 percent were sunfishes (longear, orangespotted, and green). The longear sunfish was most abundant in July when it was favored by reduced turbidity and stabilized flows

below the dam (Cross 1950). Not all warm tailwaters provide good sunfish habitat. Moser and Hicks (1970) found that sunfishes made up only 1.5 percent of the fish biomass and 3.0 percent of fish numbers in the stilling basin of an Oklahoma reservoir. Lack of cover may have been responsible for the low abundance of sunfishes. Fritz (1969) reported that bluegills made up 4.4 percent and green sunfish 2.6 percent of the angler catch in Carlyle tailwater, Illinois.

497. Sunfishes are important to the fisheries in some cool tailwaters. Longear sunfish was the most common species taken by anglers in Broken Bow tailwater, Oklahoma (36 percent of the catch), and was second in biomass (17 percent). However, more longear sunfish were captured in the river above the reservoir than in the tailwater. Weekly temperature means averaged 3.8°C lower in the tailwater than in the river upstream. Apparently the cool water and fluctuating flows influenced the harvest of sunfishes in this tailwater (Andrews et al. 1974). Cavender and Crunkilton (1974) reported that a small concentration of rock bass exists in Hoover tailwater, Ohio; the authors believed that the rock bass stay in the tailwater because of the abundance of forage fish and crayfish.

498. The food habits of bluegills and longear sunfish from Wilson Dam tailwater, Tennessee, were studied in the spring of 1977 (Warden and Hubert 1977). Fish eggs made up 67.2 percent of the total number of food items and 59.2 percent of the total volume in bluegills, and 56.1 percent by number and 3.7 percent by volume in longear sunfish. Insects were abundant in the stomachs of both species. Insects accounted for 27.1 percent by number and 32.1 percent by volume of food items in bluegills, and 23.0 percent by number and 22.2 percent by volume in longear sunfish. Insects eaten were of the orders Diptera, Coleoptera, and Trichoptera and, of these, chironomid larvae and mayfly nymphs composed 90 percent of the total number and volume. Other items found in the stomachs were decapods, larval fish, isopods, mollusks, arachnids, and annelids.

499. Growth of bluegills in Hartwell tailwater, South Carolina, did not vary from that of fish downstream or from those captured in an

unimpounded control stream. Apparently temperature fluctuations and a temperature range of 6.1 to 16.8°C in the Hartwell tailwater did not adversely affect growth (Dudley and Golden 1974), although Fry and Hanson (1968) stated that growth of warmwater fish (including bluegills) was reduced in a cold Missouri tailwater (discharge temperature 4.4-15.6°C).

Crappies

500. The white crappie and black crappie may both occur in tailwaters, and they have similar life histories.

501. Habitat. White crappies are found in ponds, lakes, reservoirs, and slow-moving streams and rivers. In reservoirs, they are often found in areas having standing timber or other cover, and at other times they frequent deeper water, commonly occurring at depths of 4.6 m or more. Young crappies are often found over open water of considerable depth. In streams, the white crappie is most abundant in the deeper pools or in backwater areas away from the main current. It avoids streams that are excessively turbid and those kept continuously cool by flow from springs.

502. The black crappie requires habitat similar to that of the white crappie except that it is less tolerant of turbidity and siltation. In reservoirs, the black crappie is noticeably more abundant in embayments fed by the clearer streams. In streams, black crappies require clear water, absence of noticeable current, and abundant cover.

503. Reproduction. Crappies begin spawning in April or May, when the water temperature rises to about 15.6°C. In reservoirs, spawning occurs in shallow areas of coves protected from wave action; many nests are sometimes concentrated in the same cove. Nests are prepared by the male on a variety of silt-free substrates in water 0.1 to 6.0 m deep. Sites with nearby logs or other large objects are favored locations for nests. The location of the nest is indicated only by the presence of the male. Eggs hatch in about 3 days and the fry remain in the nest several more days. Fry do not school after leaving the nest.

504. Food. The diet of young crappies consists mainly of zooplankton, and that of adults includes zooplankton, aquatic insects, and small fish. The proportions of these food items in the adult diet vary with locality, season, and age of the fish. Small gizzard shad and threadfin shad are important foods of adult crappies in many reservoirs.

505. Age and growth. According to Carlander (1977), the average calculated total lengths of white crappies at ages I to VI from all areas of the United States are 78, 158, 213, 257, 290, and 304 mm. Average weight of a 4-year-old white crappie is about 300 g.

506. Growth in length of black crappies is generally less than that of white crappies in the same waters (Pflieger 1975). However, since the black crappie is heavier at any given length than the white crappie, growth in weight differs little between the two species. Few crappies live more than 3 or 4 years, but occasional individuals live as long as 8 or 9 years. Maturity is reached during the second or third summer of life.

Crappies in tailwaters

507. White crappies and black crappies are important in many tailwater fisheries. When crappies are abundant in a reservoir, they are often carried through the dam and remain in the tailwater. Crappie abundance in a tailwater appears to be affected by water temperature, season, and type of dam discharge.

508. Crappies are often abundant in warmwater tailwaters and can contribute substantially to the fishery. White crappies were estimated to make up 56 percent of the angler catch at Lake of the Ozarks tailwater, Missouri, in 1965-74. A high correlation was found between estimated number of fish caught and the number of days the flood gates were open at the dam (Hanson 1977). Crappies were estimated to be 41 and 54 percent of the number and 35 and 49 percent of the weight of the fish taken by sport fishermen during warmwater releases at Barren and Nolin tailwaters, Kentucky, in 1970 and 1971 (J. P. Carter 1968a; Carter 1969). J. P. Carter (1968a) reported that before reservoir construction in 1965, crappie populations in Barren and Nolin rivers

were low and contributed little to the fishery. He attributed the increase in abundance after impoundment to fish that were produced in the reservoirs and moved downstream through the dam.

509. The occurrence of fish in stilling basins below warmwater release dams has been examined in two studies: Pfitzer (1962) collected 120,000 crappies weighing 10,884 kg from 1.0 ha of water below Douglas Dam in Tennessee on October 30, 1953; Hall and Latta (1951) stated that 23 percent of the fish found in the stilling basin below Wister Dam, Oklahoma, in August were white crappies.

510. Several investigators have reported on the movement and seasonal changes in abundance of white crappies in warm tailwaters. At Kentucky Lake tailwater in Kentucky, 3552 white crappies were captured, tagged, and released from January to December 1953. Anglers recaptured 113 fish (3.2 percent) of which 95 (84 percent) were taken within 1.6 km of the release site (Carter 1955a). A concurrent tagging study in Kentucky Lake showed little movement of white crappies (on the basis of recaptures of 5 of 1752 marked fish) through the navigation locks into the tailwater (Carter 1955a). Anglers at Lewis and Clark Reservoir and its tailwater, South Dakota and Nebraska, returned 42 tags from 288 white crappies tagged in the reservoir. Of these, 12 (28 percent) were from fish captured in the tailwater (Walburg et al. 1971). White crappies were abundant in the tailwater below Lake Carl Blackwell, Oklahoma, from October 1947 until March 1948 because flows were stable and many fish escaped from the reservoir. Between November and January, 139 white crappies were tagged and released in the tailwaters. Most tag recoveries were reported during the winter, and were made in the tailwaters. High water releases from the reservoir during March 1948 apparently caused the crappies to leave the tailwater, since only two tagged fish were captured during the subsequent spring and summer (Cross 1950). An increase in crappie abundance during fall 1965 at Barren tailwater, Kentucky, was associated with the fall reservoir drawdown and the high water discharge into the tailwater (J. F. Carter 1968b). There is a large population of white crappies and black crappies in Hoover Reservoir, Ohio, and many young

are carried over the spillway and into the tailwater (Cavender and Crunkilton 1974).

511. The change from hypolimnetic (coldwater) to epilimnetic (warmwater) release (or vice versa) at some dams has affected the abundance of crappies in tailwaters. At Barren tailwater, Kentucky, crappies composed 13.4 and 11.6 percent of the catch during hypolimnetic releases in 1968 and 1969, but 41 and 44 percent during epilimnetic releases in 1970 and 1971 (Charles and McLemore 1973). The construction of Table Rock Dam, Missouri, changed the downstream Lake Taneycomo from a warmwater to a coldwater habitat. Test netting in Lake Taneycomo before and after the coldwater intrusion showed a reduction in white crappie abundance from 6.5 to 0.9 fish per net day (Fry and Hanson 1968). Apparently the cold water made the tailwater habitat less suitable for the white crappie.

512. Small crappies are common forage for predatory fish. Combs (1979), who studied the diet of 104 adult striped bass collected from the tailwaters of Keystone Dam, Oklahoma, in 1974 through 1976, found that frequency of occurrence and percentage of total volume of white crappies in stomachs was 10.4 and 5.8 percent, respectively. Walburg et al. (1971) reported the occurrence of white crappies in stomachs of walleyes and saugers collected in Lewis and Clark tailwater, South Dakota and Nebraska.

513. Food of black crappies from Holyoke Dam tailwater, Massachusetts, in 1972 consisted mostly of spottail shiners and insects (69.8 and 27.2 percent of total food volumes); the frequency of occurrence of fish, insects, and zooplankton in stomachs was 44, 68, and 42 percent, respectively (Jefferies 1974).

514. Studies of the growth of crappies in tailwaters has received little attention. Carter (1955b) reported that white crappies in Kentucky Lake grew faster than those in the tailwater. Before deep-water releases from a Missouri reservoir converted the downstream Lake Taneycomo into a coldwater habitat in 1959, the average length of 4-year-old white crappies was 338 mm, but after the change in 1963, it was only 211 mm (Fry and Hanson 1968).

515. In a report on crappie gonadal development in tailwaters, 3 of 74 white crappies collected below a Tennessee dam, between July 29 and September 1, 1941, were immature; the rest were ripe, but none had spawned. Apparently the cold water (< 10°C) had disrupted their reproductive cycle (Eschmeyer and Smith 1943).

Percidae (Perches)

516. The perch family is one of the largest groups of North American freshwater fishes. Among them are three popular game fishes--walleyes, saugers, and yellow perch--and a large number of smaller fishes known collectively as darters. The three game fishes are represented in Europe by the same or closely related species. The darters are native only to North America.

517. The closely related walleye and sauger both occur in rivers and are important in some tailwaters. The yellow perch is most often found in lakes but it is also abundant in backwaters of large rivers. It is seldom found in small streams and usually does not occur in tailwaters and, therefore, is not discussed further here. Darters are adapted for life in swift-flowing sections of clear, rocky streams and are common inhabitants of many tailwaters. The percids are discussed under two groups--(a) walleyes and saugers, and (b) darters.

Walleyes and saugers

518. Habitat. Walleyes and saugers inhabit the open water of large, shallow lakes on slow-flowing rivers. The habitat requirements of the two species are similar, except that the sauger is more tolerant of high turbidity and is often found in areas with strong current. The sauger is more common in habitats with silted bottoms, whereas walleyes prefer habitats with gravel, bedrock, and other types of firm bottom. Tubb et al. (1965), who studied fish distribution in the Sheyenne River in North Dakota, found walleyes in pools 0.9 to 5.5 m deep, but most commonly in pools deeper than 2.4 m. The sauger was taken in only one pool, which was 2.4 m deep.

519. The sauger feeds more actively during the day, whereas the walleye is more crepuscular. The walleye is light-sensitive and is usually found in deepwater pools during the day, especially when water is clear. Both generally occur in loose aggregations of a few to many individuals. They range over a wide area, rather than restricting activities to a definite home range.

520. Reproduction. Spawning occurs at night over a 2-week period in the spring when water temperature exceeds 5.6°C. Spawning is commonly preceded by movements out of larger rivers and reservoirs into tributaries, the males moving to the spawning grounds before the females. There is some evidence that these species tend to return to a "home" spawning area in successive years. Spawning occurs on riffles or rocky areas below dams in streams and along rocky waveswept shorelines in lakes and reservoirs. Females are accompanied by several males during spawning, and eggs are scattered at random. The adhesive eggs stick to the substrate, and hatching occurs in 12 to 18 days, depending on water temperature. Newly hatched larvae are semibuoyant, and those produced in streams are therefore subject to downstream transport.

521. Food. Small crustaceans and insects are the food of walleye and sauger fry. Insects are a significant food item throughout life, but fish are the principal food of adults. They apparently eat any species of fish readily available to them.

522. Age and growth. The sauger grows more slowly than the walleye and does not attain as large a size. Fish from the northern portion of the range grow slower and live longer than those from more southern waters. Females attain greater lengths and live longer than males. Newly hatched larvae of both species are only about 7 to 8 mm in length, but under ideal conditions may attain lengths up to 254 mm by the end of the first year. Pflieger (1975) reported that the average length of walleyes from the Current River in Missouri is 200 mm at the end of the first year and 610 mm at the end of the seventh year. The usual life span is 7 or 8 years, but much older individuals are not uncommon.

523. Vasey (1967) reported that the saugers in the Mississippi River in Iowa reach a length of 145 mm in the first year and 515 mm after the seventh year. The usual life span of saugers in the South is 5 or 6 years, but some live to 12 or more years in Canadian waters.

Walleyes and saugers in tailwaters

524. Walleyes and saugers commonly occur in tailwaters below dams in many river systems. Their occurrence is often seasonal, caused by the blockage of upstream migration or passage downstream from the reservoir above. Concentration of prey fishes attracts walleyes and saugers to tailwaters.

525. Walleye numbers have increased below a number of dams in the years following construction. They are the second most numerous species in East Lynn Lake tailwater, West Virginia (Pierce 1969). They have increased in abundance in Summersville tailwater, West Virginia (Goodno 1975); below four hydropower impoundments on the Au Sable River, Michigan (Richards 1976); and in the tailwater below Stockton hydropower dam, Missouri, where they composed 28 percent of the catch by anglers in 1974 as compared with only 9 percent in 1972 (Hanson 1974).

526. Saugers are highly migratory, moving upstream as much as 380 km in 18 days, through the navigation locks in the Tennessee River main-stem dams (Cobb 1960). Blockage of upstream migration has provided significant winter and spring fisheries in most warm main-stem dam tailwaters and in some cold tributary dam tailwaters on the Tennessee River system (Pfitzer 1962). An estimated 88,703 saugers were caught between November 1959 and March 1960 in Pickwick Dam tailwater (Trenary 1962). Cobb (1960) reported there was no sauger fishery in the Tennessee River until the main-stem dams were constructed.

527. The sauger fisheries in cold tributary tailwaters of the Tennessee River system are generally smaller than those below the main-stem dams. Periodically some saugers migrate upstream from Watts Bar Reservoir and congregate in the cold Norris tailwater (Eschmeyer 1944; Eschmeyer and Manges 1945). Large numbers of saugers were also

caught in the upper 23 km of the cold Chilhowee Dam tailwater on the Little Tennessee River. In 1964 and 1965, most were taken from December to March and composed 16 percent of the creel. In the downstream portion of the tailwater, 24 to 46 km below the dam, saugers were less abundant than in the immediate tailwater, but constituted 80 percent of the anglers' catch (Boles 1969).

528. Passage of fish over dams from reservoirs upstream is also important in establishing walleye and sauger fisheries in tailwaters. An estimated 19,102 walleyes passed into an Ohio tailwater over a 5-year period (Armbruster 1962). A large percentage (42 percent) died from broken backs and pressure damage while passing through or over the dam, but 58 percent survived passage into the tailwater. Of tag recoveries from walleyes tagged in the reservoir, 30 percent came from the tailwater. Studies on the Missouri River have shown that large numbers of young-of-the-year walleyes and saugers--up to 700,000 in 24 hours--moved out of Lewis and Clark Lake, South Dakota and Nebraska, and into the tailwater (Walburg 1971). Mark-and-recapture studies indicated that some adult saugers also move from the reservoir into the tailwater (Walburg et al. 1971). Additionally, the tailwater walleye fisheries in Hoover tailwater, Ohio, and Canton Reservoir tailwater, Oklahoma, are the result of the export of fish from the reservoir (Moser and Hicks 1970; Cavender and Crunkilton 1974). A related species, the Volga pike-perch, has increased in the Kuibyshev tailwater, U.S.S.R., after successful reproduction in the reservoir (Sharonov 1963).

529. Other factors, including water depth and temperature, affect tailwater walleye and sauger fisheries. The increase in water depth with a probable increase in water temperature in the lower sections of Dale Hollow tailwater, Tennessee, due to inundation by Cordell Hull Reservoir, was followed by the appearance of both walleyes and saugers (Bauer 1976). Sport fishing success for walleyes in Lake Taneycomo tailwater, Missouri, is dependent on the water level of Bull Shoals Reservoir, which inundates the tailwater. Best catches occurred when Bull Shoals Reservoir was 0.6 to 3.0 m below power pool level. Catches

progressively declined when water levels were either above or below this range (Hanson 1969).

530. Water temperatures in some cold tailwaters have had a negative effect on walleye populations. Lowered water temperature in a North Carolina tailwater eliminated the walleye fishery (Dendy and Stroud 1949). Low water temperature in Table Rock tailwater, Missouri, has also affected the walleye catch. A rapid temperature increase of 5.6°C in the tailwater due to flood flows spilling over the dam resulted in an immediate increase in feeding activity and consequent increase in walleye catch (Fry 1965).

531. Reproduction of saugers has been adversely affected in some cold tailwaters. Saugers in a Tennessee tailwater have shown signs of resorbing eggs. This was attributed to low water temperatures, which were generally less than 10.0°C (Eschmeyer and Smith 1943).

532. Flow regulation can influence walleye reproduction hundreds of kilometres downstream. Reduced winter flows from Bennett Dam on the Peace-Athabasca River in Canada allowed the inlet to Lake Richardson to freeze, thereby delaying access of walleyes to spawning areas in the spring (Peace-Athabasca Delta Project Group 1972; Geen 1974). A similar situation was reported below the Volgograd Hydroelectric Dam, U.S.S.R. Reduced spring flows caused a deterioration of pike-perch spawning habitat far downstream in the Volga River Delta on the Caspian Sea (Orlova and Popova 1976).

533. Water-level fluctuations in tailwaters have a negative influence on sauger reproduction. Year-class strength in Fort Randall Dam tailwaters, South Dakota, was 15 times greater in years when water levels fluctuated only 0.8 m/day than in years when fluctuations were 1.4 m/day (Nelson 1968). Apparently, reduced water-level fluctuation resulted in greater survival of eggs and larvae. To increase sauger abundance, Walburg (1972) recommended that water releases from Fort Randall Dam be not less than 566 m^3/sec during the spawning and egg incubation period.

534. Walleyes have been stocked in some tailwaters where natural reproduction does not occur. A 26-km stretch of river below the

Boysen Unit Dam, Wyoming, has provided a good walleye fishery as a result of stocking (U. S. Bureau of Sports Fisheries and Wildlife 1969). Hicks (1964) recommended stocking walleye fingerlings instead of walleye fry in Tenkiller tailwater, Oklahoma, because of unsuitable zooplankton supplies caused by intermittent water releases. The recommended stocking of fingerlings was apparently successful, since both walleyes and saugers now occur in the tailwater (Deppert 1978).

535. Food habits and growth of walleyes and saugers in tailwaters are not well documented. An examination of six walleyes collected from Holyoke Dam tailwater, Massachusetts, showed that fish made up 96 percent of the total volume of food in stomachs (Jefferies 1974). Saugers in Chilhowee tailwater, Tennessee, preyed heavily on stocked rainbow trout during the spring spawning run (Boles 1969). Food of walleyes and saugers from Lewis and Clark tailwaters, South Dakota and Nebraska, consisted primarily of gizzard shad, emerald shiners, yellow perch, white bass, and white crappies (Walburg et al. 1971). The growth of walleyes and saugers in Lewis and Clark Lake tailwater was superior to that in the reservoir; for fish of similar lengths, the weights of walleyes and saugers were respectively 7 and 12 percent greater in the tailwater.

Darters

536. According to Bailey et al. (1970), 109 species of darters are found in the United States and Canada. Comparatively few are mentioned in the tailwater literature. A general description of darter life history is presented because of the large number of species.

537. Habitat. Most darters are found in clear, small- to medium-sized streams with permanent flow and clean, gravelly, or rocky bottoms. They are most often found in the deeper sections of riffles, but also occur in rocky pools having no perceptible current. Some species are more tolerant to turbidity than others. The young of most species can be found in quiet-water areas associated with leaves, sticks, and organic debris.

538. Darters are adapted for life in swift-flowing streams. They sink immediately to the bottom when they stop swimming, and the press of the current against their enlarged pectoral fins tends to hold them in place. Darters are usually found beneath or between rocks and are thus afforded protection from the direct action of the current. When moving from place to place, they proceed by a series of short darts.

539. Reproduction. Most darters usually spawn in late spring over a sand or gravel bottom in water about 0.3 m deep having moderate current. Eggs are laid and fertilized in a depression on the stream bottom, where they hatch in about 21 days at 21°C. Eggs and larvae receive no parental protection.

540. Some darter species attach eggs to strands of filamentous algae or aquatic mosses and males establish territories. Breeding males of still other species seek out and occupy cavities beneath rocks. Ripe females enter the cavity and deposit their eggs, where they adhere to the underside of the rock. The male stays with the eggs until they hatch.

541. Food. Darters are carnivorous, feeding principally on insects and other small aquatic invertebrates.

542. Age and growth. Lengths of adult darters other than logperch usually range from 64 to 89 mm, with a maximum of about 100 mm. Males grow more rapidly and attain a larger size than females. Most are mature in the first spring after hatching and few live longer than 3 years. The logperch, the largest darter, usually ranges in length from 102 to 152 mm, but sometimes attains 178 mm.

Darters in tailwaters

543. Darters have not been studied extensively in tailwaters. They flourish in a variety of environments, and some have become established in cold tailwaters. Many darter species, particularly the orangethroat darter, rainbow darter, and logperch, are abundant in Beaver tailwater, Arkansas (Brown et al. 1968; Bacon et al. 1969; Hoffman and Kilambi 1970). Their abundance may be due to the unstable composition of the fish population in this relatively new tailwater.

Darter numbers are reduced in older tailwaters in the same drainage (Brown et al. 1968; Hoffman and Kilambi 1970).

544. The relatively low water temperatures (14.4-21.7°C), low turbidities, mixed gravel-bedrock substrates, and high dissolved oxygen levels in Hoover tailwater, Ohio, provide excellent habitat for some darter species. The logperch, greenside darter, rainbow darter, and banded darter are all abundant, and the blackside darter, johnny darter, and fantail darter also occur there (Cavender and Crunkilton 1974).

545. The logperch, gilt darter, and banded darter were all abundant in the cold Chilhowee tailwater in Tennessee. The logperch was also numerous in the cold Norris tailwater (Hill 1978). The tessellated darter was dominant in the cold Rocky Gorge Dam tailwater, Maryland (Tsai 1972). The orangethroat darter was the second most abundant species in the cold tailwater below Canyon Dam, Texas. The reduced temperatures in this tailwater appear to have extended the winter and spring breeding season of this species, and reproduction now occurs throughout the year (Edwards 1978).

546. Only one report on the age and growth of darters in tailwaters was found. Tsai (1972), who studied the tessellated darter in Rocky Gorge Dam tailwater in 1967, found that the mean standard lengths of females at ages I, II, and III were 35, 47, and 55 mm; males were 37 mm long at age I and 50 mm at age II.

Sciaenidae (Drums)

547. The drum family contains many important marine fishes; only one is a freshwater species, the freshwater drum.

Freshwater drum

548. Habitat. This fish is found in large, shallow lakes and large, slow-moving rivers. It is usually found in the larger pools of streams and in lakes and reservoirs at depths of 9.0 m or more. The freshwater drum avoids strong current, is usually found near the bottom, and is tolerant of high turbidity. It is particularly common in the Missouri and Mississippi rivers and the downstream sections of their

major tributaries. It is also common in Lake Erie and in many reservoirs.

549. Reproduction. Spawning of the freshwater drum occurs in late spring or early summer, when water temperatures reach about 18°C. Spawning occurs over a period of about 6 weeks (Swedberg and Walburg 1970). Eggs are fertilized in the open water and float until hatching. They hatch in about 36 hours at 21°C; newly hatched larvae are 3.2 mm long. The larvae are semipelagic until they are at least 15 mm long. The wide distribution of the freshwater drum in flowing-water systems is related to the pelagic state of their eggs and larvae.

550. Food. The diet of freshwater drum consists mainly of fish, crayfish, and immature aquatic insects; mollusks are eaten if available. Young of the year eat mostly zooplankton and chironomids; as fish increase in size, larger aquatic insects become important.

551. Age and growth. In Missouri streams, freshwater drum average 112 mm in length by the end of the first year of life and 206, 269, 315, 353, and 378 mm in succeeding years (Purkett 1958b). On the average, a 330-mm fish weighs about 450 g and a 400-mm fish about 900 g. Most drum caught by fishermen weigh 900 g or less, but individuals weighing up to 15.9 kg are occasionally taken. The maximum life span is at least 13 years.

Freshwater drum in tailwaters

552. The role of freshwater drum in tailwaters has not been studied extensively. Several reports deal with their occurrence in warm and cold tailwaters. They are relatively common in the warm Keystone Dam tailwater, Oklahoma, where they are eaten by striped bass (Combs 1979). They are abundant in Lewis and Clark Lake, a main-stem Missouri River reservoir on the South Dakota-Nebraska border, and large numbers of young of the year less than 25 mm long pass into the tailwater with the discharge during the summer (Walburg 1971). In spite of the large numbers of young lost from the reservoir, adults are relatively uncommon in this warm tailwater (Walburg et al. 1971). Apparently few of the young carried downstream in the river flow later return to the tailwater. Freshwater drum made up 10 percent

of the total sport catch in the cool Pomme de Terre tailwater, Missouri, from 1965 through 1974 (Hanson 1977). They were also common in the cold Tenkiller Dam tailwater, Oklahoma (Deppert 1978). The numbers of freshwater drum in a Missouri tailwater have declined in recent years because water temperatures have decreased since completion of the upstream dam (Hanson 1969).

Cottidae (Sculpins)

553. The sculpins are bottom-living, primarily marine fishes, of arctic and temperate seas; several genera are found in fresh waters of the northern hemisphere. This discussion will be limited to the mottled and banded sculpins, which occur in some streams.

Sculpins

554. Habitat. The two sculpin species often occur together because their requirements are similar. The mottled sculpin is usually found in streams with clear, cold water, in both riffles and pools with bottom types ranging from silt to gravel and rock. Generally, it is most abundant in cover such as coarse rock or thick growths of water-cress. The banded sculpin tolerates higher temperatures than the mottled sculpin and is the more abundant of the two in larger and warmer streams. Sculpins live on the bottom, spending considerable time lying motionless in one spot and moving in short, quick dashes.

555. Reproduction. The mottled sculpin spawns in the spring when water temperature reaches about 10°C. The adhesive eggs are deposited in clusters of about 200 on the undersides of stones. The incubation period is 3 to 4 weeks and the male remains near the nest until the fry disperse.

556. Food. Larval aquatic insects are the main diet of sculpins. Cottids are predaceous, but they do not feed extensively on eggs and young of trout, as is sometimes claimed (Pflieger 1975).

557. Age and growth. The mottled sculpin is 28 to 36 mm long when one year old. It probably does not mature until its third or fourth summer of life. Adults are commonly 60 to 90 mm long and the

maximum is about 115 mm. The banded sculpin is somewhat larger. Adults are commonly 65 to 130 mm long and the maximum is 185 mm or more.

Sculpins in tailwaters

558. Sculpins have not been extensively studied in tailwaters, although they are numerous in some cold tailwaters. Pfitzer (1962) noted that sculpins became important as forage in many cold tailwaters of the Tennessee Valley when the number of minnow species declined. Both the banded sculpin and mottled sculpin have become numerous in Chilhowee tailwater, Norris tailwater, and Apalachia tailwater (Hill 1978). The mottled sculpin is the most abundant species in both the Norfork and Bull Shoals tailwaters in Arkansas (Brown 1967; Hoffman and Kilambi 1970). Sculpins are also abundant in the McKenzie River System, Oregon, where they are found in the cold tailwaters of four hydropower facilities and one flood-control dam (Hutchison et al. 1966).

559. Cottids are not found in all tailwaters. The mottled sculpin has disappeared below four hydropower dams on the Au Sable River, Michigan (Richards 1976), and were rarely collected during 1966 studies in the cold Beaver tailwater, Arkansas (Brown 1967).

560. Sculpins are highly susceptible to stranding during large water fluctuations because of their sedentary behavior. A total of 55 sculpins were found stranded in three 0.82-m^2 sections of the tailwater below a Wyoming dam. It was recommended that flow decreases not exceed 2.8 m^3/sec/day, to allow for fish migration out of the area (Kroger 1973).

561. Overall, reductions in flow do not appear to affect sculpin survival. The piute sculpin (formerly eagle sculpin) is one of the surviving native species in the Granby Dam tailwater, Colorado, in spite of large flow reductions.

562. Sculpins appear to reproduce successfully in a number of tailwaters. The banded sculpin was the only fish species able to reproduce in the cold Dale Hollow tailwater, Tennessee; no young of the year other than sculpins were observed (Little 1967). The partial inundation of a tailwater by a downstream reservoir beginning in about

1970 seriously reduced the abundance of the banded sculpin, and the species is now infrequently collected (Bauer 1976).

563. The food habits of sculpins in tailwaters are not well known. The common bullhead, a cottid which occurs in Cow Green tailwater on the Tees River, United Kingdom, exhibited a feeding shift following impoundment of the reservoir. The reduction of Plecoptera caused the adults to begin feeding on mollusks, and the fry shifted to Diptera and Ephemeroptera (Crisp et al. 1978). The food of the banded sculpin in Dale Hollow tailwater, prior to inundation by the downstream Cordell Hull Reservoir, consisted of Diptera, Coleoptera, Isopoda, crayfish, and small trout. The sculpins did not eat Cladocera, which were abundant in the reservoir discharge (Little 1967).

PART VIII: CONCLUSIONS

564. The construction of an impoundment alters the biological, chemical, and physical characteristics of the stream environment below the reservoir. Many of the biological changes are a direct result of dam construction, and include blockage of upstream fish migration, inundation of spawning grounds, and the interruption of downstream invertebrate drift. In addition, the tailwater biota is influenced by the characteristics of the impoundment and the faunal and geomorphic characteristics of the preimpoundment stream.

565. Physical and chemical characteristics in the tailwater are primarily determined by the volume and timing of water released and by the depth from which water is withdrawn from the reservoir. The effects of these releases are further modified within the tailwater by inflows from downstream tributaries and groundwater, riparian vegetation, atmospheric conditions, and physical characteristics of the streambed. The tailwater biota reflects interactions between the native or introduced organisms and the physical and chemical conditions in the tailwater.

Effects of Hypolimnetic Release on Downstream Biota

566. The depth of the discharge is of primary importance in determining the tailwater environment below stratified reservoirs. The release depth affects water temperatures, dissolved gas concentrations, nutrients, turbidity, and the presence of toxic concentrations of some dissolved substances in the tailwater. These factors have a profound effect on the tailwater biota.

567. Maximum and average water temperatures are generally colder in the tailwater below a hypolimnetic release reservoir than in the unimpounded stream. The effects of these coldwater releases are similar on both warmwater and coldwater streams but are more severe for the warmwater streams. The reduced water temperatures may fall below the tolerance levels of certain native species of invertebrates and fish.

Lowered water temperature can increase the competition between native species and introduced organisms adapted to the colder environment. The result may be the loss of some native species from the tailwater.

568. A change in the seasonal water temperature pattern also occurs in tailwaters. Water in hypolimnetic discharges is colder than that in the unimpounded stream during the summer and warmer during the winter. Delays in spring warming because of cold hypolimnetic releases may alter the reproduction, hatching, emergence, and development of many invertebrates and fish. The altered temperature regimes may disrupt the life cycles of some insect species and cause them to emerge during the winter or prevent them from hatching in the spring. Some fishes may not reproduce because the cold water disrupts their physiological development and eliminates the temperature stimulus to spawn. Some may spawn several weeks late, retarding egg and larval development. The smaller young are subject to more intense interspecific competition and reduced over-winter survival.

569. The temperature of cold tailwaters below hypolimnetic release dams built on warmwater streams eventually returns to ambient as waters proceed downstream. The biota in the downstream section closely resembles that in the natural unimpounded stream. A transitional zone may exist between the cold tailwater and the warm downstream river that may not be readily inhabited by either coldwater or warmwater organisms. This transitional zone is often larger than the immediate tailwater (Hulsey 1959).

570. Hypolimnetic releases into coldwater streams generally do not have a drastic effect on the stream biota. Water temperatures in these tailwaters generally remain within the tolerance levels of the coldwater organisms that inhabited the original stream. Temperatures may sometimes be reduced below the tolerance level of certain organisms which may disappear from the immediate tailwater. This situation may also result in some redistribution of insects and fish. For example, chironomids and simuliids have replaced most other insect species, and brook trout have replaced rainbow and brown trout in some tailwaters.

571. The volume of cold, hypolimnetic water stored in the reservoir and the loss of daily temperature fluctuations in the tailwater affects downstream biota. Some reservoirs lack sufficient storage capacity of cold, hypolimnetic water to maintain coldwater releases throughout the summer and fall. Inadequate storage capacity may result in the change from a coldwater to a warmwater tailwater during the latter part of the summer. This change significantly affects the tailwater biota, since coldwater organisms cannot survive in the warm waters of late summer and warmwater organisms cannot reproduce or grow in the cold waters which occurred earlier in the year.

572. The loss of diurnal fluctuations in water temperature may remove the temperature stimulus necessary for normal progression of invertebrate life processes. Some invertebrates may disappear but other better adapted species usually replace them. Invertebrate populations in these stressed environments often display low diversities and high densities.

573. Low dissolved oxygen concentrations in tailwaters below stratified deep-release reservoirs may cause physiological stress in the aquatic community and limit fish and invertebrate diversity. Biological decomposition in the hypolimnion of some reservoirs during the summer eliminates most of the dissolved oxygen and results in the release of deoxygenated water. If insufficient reaeration occurs in the outlet works, invertebrates may enter the drift and fish may actively migrate downstream. In extreme cases, lack of adequate dissolved oxygen has been responsible for the die-off of fish in tailwaters. In most tailwaters, however, turbulent flow over riffles rapidly increases the dissolved oxygen concentration as the water proceeds downstream.

574. Nutrients which enter a reservoir may be used by the reservoir phytoplankton or may settle into the hypolimnion. The dissolved nutrients which accumulate in the hypolimnion, either as a result of the decomposition of organic matter or directly from the watershed, are flushed into the tailwater during release of hypolimnetic water and may enhance primary productivity in the tailwaters. The additional nutrients may increase periphytic algal production in the tailwater and,

consequently, increase the numbers of invertebrates feeding on or living in the algae.

575. Toxic levels of reduced substances, including iron, manganese, hydrogen sulfide, and ammonia, may be formed in the hypolimnion of a reservoir during low oxygen conditions. It is possible for these substances to be released into the tailwater at levels which may stress both the invertebrate and fish populations.

576. Turbidity is usually reduced in tailwaters below deep-release dams and organisms which are adapted to turbid waters may be at a competitive disadvantage. For example, reduced turbidity favors trout and other clear-water species over rough fish. In some instances, however, turbid inflows move through the reservoir as a density current and are released into the tailwater.

Effects of Epilimnetic Release on Downstream Biota

577. Reservoirs with epilimnetic releases are generally less disruptive to tailwater biota than are those with hypolimnetic releases. Warmwater streams are subject to only minor temperature changes as a result of the construction of an epilimnetic release reservoir. The water temperature of the discharge is usually within the tolerance limits of the native warmwater stream species and does not affect their survival. Additionally, some species of fish and invertebrates may be transported out of the reservoir and added to the tailwater biota. Fish common in the reservoir often predominate in the tailwater. Epilimnetic discharge from a dam built on a coldwater stream usually has a higher summer and autumn temperature than the original stream. The warmer discharges may cause changes in the biota of the tailwater. Coldwater species (plecopterans and trout) may be eliminated by temperatures exceeding their tolerance levels. Elevated temperatures also may allow rough fish (carp and suckers) to outcompete many of the native or introduced species (trout).

578. Low dissolved oxygen concentrations rarely limit the biota below surface-release reservoirs. High levels of photosynthesis in

the reservoir epilimnion, gas exchange during passage of water from the reservoir, and downstream turbulent flow all increase concentrations of dissolved oxygen in the tailwater. Toxic concentrations of iron, manganese, and hydrogen sulfide are rarely encountered since these materials are products of anoxic conditions in the hypolimnion.

579. Spillway releases from high dams, particularly in years of high flow, can cause gas supersaturation in tailwaters and result in mortality to fish and invertebrates. Low downstream temperatures and a laminar flow inhibits the dissipation of the dissolved gases back to the atmosphere. Gas supersaturation has been noted in the tailwater below a dam on a warmwater stream in the central United States, but the problem is most common at high dams on the larger rivers of the Pacific Northwest. Nitrogen supersaturation and nitrogen embolism generally do not occur at lowhead dams.

580. Epilimnetic discharges are generally low in dissolved nutrients, since particles (algae, suspended material) containing or sorbing nutrients settle into the hypolimnion. This loss of nutrients results in reduced primary productivity in the immediate tailwater. However, the export of insects, phytoplankton and zooplankton from the reservoir often compensates for this reduction. The exported organisms are often used as food and may increase the numbers of fish congregating below the dam. Many of the invertebrates may flourish below surface-release reservoirs because of the export of plankton and other suspended organic matter from the reservoir.

581. Many reservoir fish move into the tailwater either through the turbines or over the spillway. Tailwater populations of shad, sunfishes, suckers, pikes, and some percids may be maintained through export from the reservoir. In addition, native stream fishes often concentrate here, and consequently sport fishing in tailwaters is sometimes excellent. Tailwater fisheries are most successful in spring and early summer because of migrations related to spawning. Sustained low flows adversely affect fishing success.

Effects of Water Release Patterns on Downstream Biota

582. The timing and volume of water released from a dam may severely limit or enhance the tailwater biota. Changes in the flow patterns after dam construction include seasonally stabilized flows, sustained high flows (with reduced peak flows) during high water periods, *minimum* flows during dry periods, and diel fluctuating flows below hydropower facilities. The effect of these flow changes on the biota may, however, be masked by other factors such as temperature, dissolved oxygen, and toxic levels of reduced substances.

583. The tailwaters below most nonhydropower reservoirs have a more stable annual flow regime than that in unimpounded streams. The stabilized flows that result from both a reduction in the intensity of floods and the maintenance of flows during low-water periods provide a less variable habitat. Dense algal mats, often associated with stabilized flows, may inhibit the production of some native invertebrate species that prefer rock substrates. However, the additional habitat and food supply provided by the algal mats generally attract new invertebrate taxa that become an important part of the food web, but species feeding on allochthonous material become less abundant. Nesting fishes may reproduce more successfully in a stabilized tailwater. Stable flows may, however, be detrimental to fish that require moderate flow variation to initiate spawning activities.

584. The effects of high flows (floods) in natural streams have been described by several authors (Tarzwell 1938; Seegrist and Gard 1972; Ryck 1976). High flows in tailwaters are generally less intense than in unaltered streams but are continued over a longer time. The effects of high flows on tailwater fishes are partly dependent on the tailwater physiography. If the tailwater has deep pools, sufficient cover, or backwater areas for fish shelter, high flows are less detrimental to fish populations than if the tailwater has little physical variability. High flows during the reproductive period of fish can scour the stream bottom and destroy the eggs and larvae and reduce

reproductive success, especially in unsheltered areas. Increased discharges may cause catastrophic drift of benthos, causing a substantial decrease in benthic standing crops. High flows can be beneficial in some tailwaters as they flush sediment from the interstices of the rubble substrate and supply food and oxygen to benthic invertebrates.

585. Fall drawdown of flood control reservoirs increases flows into the tailwater. This drawdown usually occurs after reservoir destratification, when fish and other organisms are more evenly distributed within the reservoir. Many young-of-the-year and older fish may be lost from the reservoir during this time, causing an increased abundance in the tailwaters. The effects of the increased flows on the resident stream fishes in the tailwater, both during the reservoir drawdown and for sustained periods after flood flows, are largely unknown. The increased flows may initially produce catastrophic effects on stream invertebrates, but the benthic community gradually stabilizes as the remaining flow-tolerant species adjust to the prevailing conditions. Higher flows extend the influence of the reservoir discharge downstream.

586. The subject of minimum flows is one of the most widely studied aspects of regulated streams. During the dry season of late summer and fall, minimum flows are often maintained below dams to provide aquatic habitat for the survival of invertebrates and fish. The habitat that remains, however, is usually of decreased quality and quantity. Reduced habitat increases interspecific competition for space and food among fish and among invertebrates. Both groups experience physiological stress and reduced production during low flows. Low flows in tailwaters reduce water velocities and associated detrital material, and thus food and oxygen for benthic organisms are also reduced. Low flows allow silt and detritus to accumulate in the tailwater from streamside runoff. This material may be beneficial to the productivity in the tailwater if not present in excessive quantities. In coldwater streams, minimum flows from deep-release reservoirs

often maintain water temperatures within tolerance levels for coldwater species (e.g., trout).

587. Irrigation storage reservoirs impound winter and spring runoff, with a consequent reduction in tailwater flows. Winter dewatering of the tailwater reduces overwinter survival of many organisms by limiting habitat and exposing them to harsh winter conditions. Poor survival of trout has been documented in streams dewatered in winter. Dewatering in the spring probably affects the reproduction of some fishes by reducing both the stimulus to spawn and the availability of spawning habitat.

588. Below hydropower dams, large diurnal flow fluctuations most often have a destructive influence on the tailwater biota and create an unstable, highly variable downstream habitat. The extreme variation in flow scours the tailwater and displaces both fauna and flora. Species with narrowly defined environmental requirements are eliminated from these tailwaters. During power generation, high water velocities cause streambed and bank instability and habitat degradation. The stream may be subject to increased turbidity, and algal and macrophytic growth is discouraged. The widely fluctuating flows discourage the establishment of streamside vegetation and other aquatic plants. The benthic food base is radically reduced and some species may be eliminated. A "zone of fluctuation" is permanently established where no production takes place because of periodic streambed exposure during nonpower cycles.

589. Fluctuating flows disrupt the spawning and reproductive success of some fish species by destroying nests and sweeping away unsheltered eggs and fry. Only fish adapted to high water velocities are able to sustain their populations in tailwaters below hydropower dams. Stranding and desiccation of many species of invertebrates, fish eggs, salmonid fry, and sculpins have been reported. Invertebrates located in fluctuating tailwaters may attain community equilibrium, provided they are able to adapt to the variations in flow.

590. The release of large volumes of cold hypolimnetic water during power generation maintains a cold tailwater environment below some southern reservoirs. However, during nongenerating periods, the

small volume of water released may warm rapidly due to solar radiation and exposure to warm air temperatures. The thermal tolerance of some fish and invertebrates may be exceeded during these periods, and the organisms either move out of the tailwater or die. The increased water temperatures may be beneficial to some species, such as carp and smallmouth bass, that compete with coldwater fishes. Despite the fluctuating flows encountered below hydropower dams, many excellent trout fisheries have developed in these waters. The quality of the fishery depends on the habitat suitability for trout, which includes cold water, adequate flow, plentiful cover and food.

Past Tailwater Research and Suggestions for Future Study

591. Review of the available literature revealed that the present understanding of biological problems in tailwaters is far from complete. Current research being funded or conducted by various groups, including the U. S. Army Corps of Engineers, Tennessee Valley Authority, U. S. Water and Power Resources Service (formerly Bureau of Reclamation), and the U. S. Fish and Wildlife Service, may provide the necessary information to overcome the inadequacy of the literature.

592. Most tailwater research has been narrow in scope. Usually, the study of the biota in a tailwater has been limited to the compilation of lists of invertebrate species and fish species or creel census. It has sometimes been assumed that a major change in one physical factor (e.g., temperature, flow, etc.) has caused a change in the tailwater biota. However, the more comprehensive investigations needed to confirm these assumptions have rarely been conducted.

593. The few studies that have been directed toward determining the causes for observed changes in tailwater biota have generally been the result of acute short-term problems (e.g., fish kills caused by gas supersaturation or reduced dissolved oxygen). The more subtle changes resulting in the disappearance of a species or change of species composition in tailwaters have generally not been determined. As an example, the loss of a fish species in cold tailwaters has been

attributed to the reduction in temperature. What is usually not known is which stages of the fish's life cycle were affected by the lowered temperature. Reduced temperatures may have had any of several effects or combinations of effects: (a) prevented the initiation of spawning activity, (b) inhibited the hatching of eggs, (c) impeded the growth of fry, (d) destroyed a required food source, (e) provided other species with a competitive advantage, or (f) simply been below the tolerance limits of the affected species. If the "weak link" in the life cycle of the species was known, it might be possible to release water of a more favorable temperature during the critical period (e.g., releasing water of a warmer temperature until egg hatching is completed).

594. It is improbable that changes in species composition were due solely to one factor, such as a reduction in temperature. Changes in the tailwater biota are more likely due to the alteration of a number of factors such as temperature, flow, habitat availability, food abundance, and the levels of turbidity, dissolved gases, and certain chemicals. Additionally, the degree to which these alterations affect the biota in each tailwater may be highly variable. The biota in two apparently similar tailwaters may react differently to similar changes in chemical and physical factors because of differences in project location, construction, and operation. Indeed, it is possible that in some tailwaters the assumed cause of the faunal changes (e.g., temperature reduction) may not have had any real effect, but simply masked the actual causative factors.

595. Studies are needed to determine the tailwater chemical and physical properties that cause changes in diversity and abundances in the biotic community. Such studies should investigate all parts of the tailwater ecosystem and must include continuous (i.e., daily) monitoring of major chemical and physical variables and periodic sampling of the tailwater biota (i.e., periphyton, plankton, benthos, fish). Once sufficient information on the chemical and physical environment of a tailwater is obtained, it should be possible to relate this information to observed changes in the biotic community with appropriate statistical analyses.

596. In addition to determining which chemical and physical factors act to alter the biotic community, further more intensive, limited studies will be needed to discover how these factors act on the most seriously affected members of the biota. Only by determining how the affected tailwater organisms are influenced will it be possible to suggest improvements in the current tailwater management plan; for example, how a valuable warmwater fish species is influenced below a hypolimnetic release, hydropower dam. It may be determined that the disappearance of this species is most closely correlated with diurnal flow and temperature fluctuations and delayed seasonal warming. More narrowly defined studies may determine that fish spawning has been delayed because of a lack of adequate thermal stimulus and that fish egg hatching and invertebrate food production have declined because of the periodic drying of spawning beds and riffle areas. Ultimately, it will be up to the managing agency to determine if any of the suggestions might be implemented within the context of an overall reservoir management plan.

597. The type of intensive study just discussed is only useful for understanding the problems of an individual tailwater being investigated. It would be helpful in the future to have a generalized conceptual model of each major tailwater type to assist in the recognition of tailwater problems without resorting to large-scale intensive studies. Such a conceptual model must provide a clear understanding of how the major chemical, physical, and biological variables relate to and interact with each other.

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APPENDIX A: ALPHABETICAL LIST OF THE 113 TAILWATERS MENTIONED IN THE TEXT WITH LOCATION BY RIVER AND STATE, PROVINCE, OR COUNTRY

Tailwater	River	State(s), Province(s) or Country
Antelope	Jordan Creek	Oregon
Apalachia	Hiwasse	Tennessee
Augusta	Kennebec	Maine
Barren	Barren	Kentucky
Beaver	White	Arkansas
Bennett	Peace, Athabasca	Alberta, British Columbia
Berlin	Mahoning	Ohio
Big Bend	Missouri	South Dakota
Bliss	Snake	Idaho
Blue Lake	Sawmill Creek	Alaska
Blue Mesa	Gunnison	Colorado
Boulder (Hoover)	Colorado	Nevada, Arizona
Boysen Unit	Wind	Wyoming
Broken Bow	Mountain Fork	Oklahoma
Buckhorn	Kentucky	Kentucky
Bull Shoals	White	Arkansas
Caballo	Rio Grande	New Mexico
Calderwood	Little Tennessee	Tennessee
Canton	North Canadian	Oklahoma
Canyon	Guadelupe	Texas
Cape Horn Diversion	Eel	California
Carl Blackwell	Stillwater Creek	Oklahoma
Carlyle	Kaskaskia	Illinois
Center Hill	Caney Fork	Tennessee

(Continued)

Tailwater	River	State(s), Province(s) or Country
Cherokee	Holston	Tennessee
Chilhowee	Little Tennessee	Tennessee
C. J. Strike	Snake	Idaho
Clark Canyon	Beaverhead	Montana
Clearwater	Black	Missouri
Conowingo	Susquehanna	Maryland
Cooke	Au Sable	Michigan
Cordell Hull	Cumberland	Tennessee
Cottage Grove	Coast Fork Willamette	Oregon
Cow Green	Tees	United Kingdom
Coyote	Russian	California
Cumberland	Cumberland	Kentucky
Dale Hollow	Obey	Tennessee
Davis	Colorado	Arizona, Nevada
Dexter	Middle Fork Willamette	Oregon
Diversion (unnamed)	Blacktail Creek	Montana
Dorena	Row	Oregon
Douglas	French Broad	Tennessee
East Lynn	Twelvepole Creek	West Virginia
Elephant Butte	Rio Grande	New Mexico
Ennis	Madison	Montana
Fern Ridge	Long Tom	Oregon
Five Channels	Au Sable	Michigan
Flaming Gorge	Green	Utah, Colorado
Fontana	Little Tennessee	North Carolina
Fontenelle	Green	Wyoming
Foote	Au Sable	Michigan
Fort Randall	Missouri	South Dakota

(Continued)

Tailwater	River	State(s), Province(s) or Country
Glen Canyon	Colorado	Arizona
Granby	Colorado	Colorado
Hartwell	Savannah	Georgia, South Carolina
Hebgen	Madison	Montana
Hog Park	Hog Park Creek	Wyoming
Holyoke	Connecticut	Massachusetts
Hoover	Big Walnut Creek	Ohio
Jackson Lake	Snake	Wyoming
Kentucky	Tennessee	Kentucky
Keystone	Arkansas	Oklahoma
Kuibyshev	Volga	U.S.S.R.
Lake of the Ozarks (Bagnell)	Osage	Missouri
Lewis and Clark (Gavins Point)	Missouri	Nebraska, South Dakota
Libby (Koocanusa)	Kootenai	Montana
Little Goose	Snake	Washington
Little Grassy	Crab Orchard Creek	Illinois
Lock and Dam 12	Mississippi	Illinois, Iowa
Lookout Point	Middle Fork Willamette	Oregon
Loramie	Loramie	Ohio
Low head (unnamed)	Maquoketa	Iowa
Lower Salmon Falls	Snake	Idaho
McNary	Columbia	Oregon, Washington
Mingeshaur	Kura	U.S.S.R.
Mio	Au Sable	Michigan
Morrow Point	Gunnison	Colorado
Narvskaya	Narova	U.S.S.R.

(Continued)

Tailwater	River	State(s), Province(s) or Country
Navajo	San Juan	New Mexico
Nolin	Nolin	Kentucky
Norfork	North Fork	Arkansas
Norris	Clinch	Tennessee
Oahe	Missouri	South Dakota
Owyhee	Owyhee	Oregon
Percha Diversion	Rio Grande	New Mexico
Pickwick	Tennessee	Tennessee
Pomme de Terre	Pomme de Terre	Missouri
Roanoke Rapids	Roanoke	North Carolina
Rob Roy	Douglas Creek	Wyoming
Rocky Gorge (Triadelphia)	Patuxent	Maryland
Rough	Rough	Kentucky
Shand	Grand	Ontario
Shasta	Sacramento	California
South Holston	South Fork Holston	Tennessee
Stockton	Sac	Missouri
Summersville	Gauley	West Virginia
Table Rock	White	Missouri
Taneycomo	White	Missouri
Taylor Park	Taylor	Colorado
Tenkiller	Illinois	Oklahoma
Tiber	Marias	Montana
Twin Valley	Mill Creek	Wisconsin
Upper Salmon Falls	Snake	Idaho
Urieville	*	Maryland

*State owned ponds.

(Continued)

Tailwater	River	State(s), Province(s) or Country
Vir	Svratka	Czechoslovakia
Volgograd	Volga	U.S.S.R.
Watauga	Watauga	Tennessee
Watts Bar	Tennessee	Tennessee
Wilson	Tennessee	Alabama
Wister	Poteau	Oklahoma
Wye	*	Maryland
Wyman	Kennebec	Maine
Yellowtail	Bighorn	Montana

*State owned ponds.

APPENDIX B: LOCATION OF 105 RESERVOIR TAILWATERS IN THE UNITED STATES MENTIONED IN THE TEXT

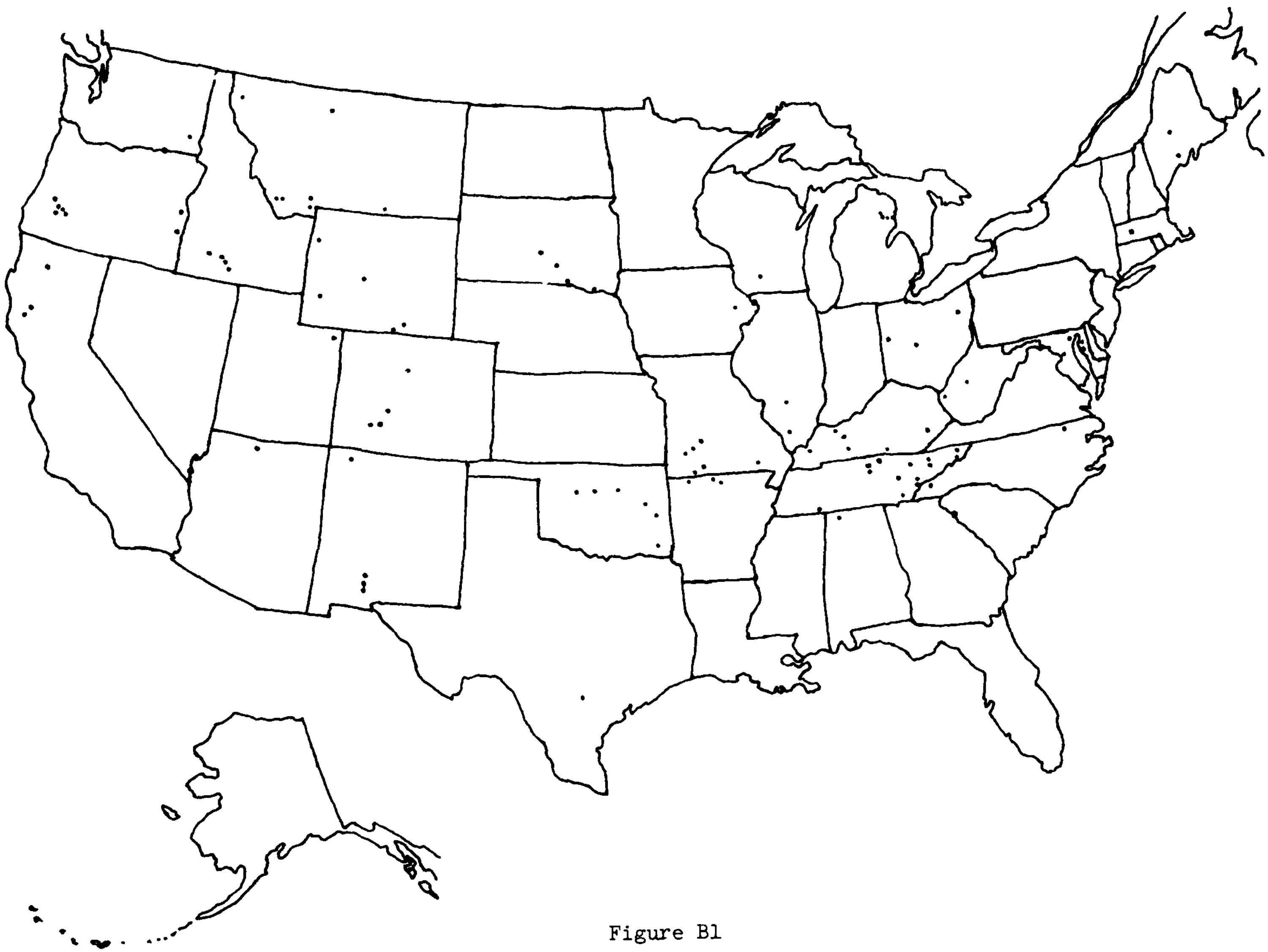

Figure B1

APPENDIX C: COMMON AND SCIENTIFIC NAMES OF FISHES MENTIONED IN THE TEXT, ARRANGED BY FAMILY

Part I: Fishes from North American Tailwaters

Polyodontidae	
Paddlefish	*Polyodon spathula* (Walbaum)
Clupeidae	
Skipjack herring	*Alosa chrysochloris* (Rafinesque)
American shad	*Alosa sapidissima* (Wilson)
Gizzard shad	*Dorosoma cepedianum* (Lesueur)
Threadfin shad	*Dorosoma petenense* (Günther)
Salmonidae	
Coho salmon	*Oncorhynchus kisutch* (Walbaum)
Cutthroat trout	*Salmo clarki* Richardson
Rainbow trout	*Salmo gairdneri* Richardson
Brown trout	*Salmo trutta* Linnaeus
Brook trout	*Salvelinus fontinalis* (Mitchill)
Esocidae	
Grass pickerel	*Esox americanus vermiculatus* Lesueur
Northern pike	*Esox lucius* Linnaeus
Muskellunge	*Esox masquinongy* Mitchill
Chain pickerel	*Esox niger* Lesueur
Cyprinidae	
Chiselmouth	*Acrocheilus alutaceus* Agassiz and Pickering
Stoneroller	*Campostoma anomalum* (Rafinesque)
Carp	*Cyprinus carpio* Linnaeus
Humpback chub	*Gila cypha* Miller
Bonytail	*Gila elegans* Baird and Girard
Roundtail chub	*Gila robusta* Baird and Girard
Speckled chub	*Hybopsis aestivalis* (Girard)
Bigeye chub	*Hybopsis amblops* (Rafinesque)
Streamline chub	*Hybopsis dissimilis* (Kirtland)
Peamouth	*Mylocheilus caurinus* (Richardson)
Hornyhead chub	*Nocomis biguttatus* (Kirtland)
River chub	*Nocomis micropogon* (Cope)
Golden shiner	*Notemigonus crysoleucas* (Mitchill)
Texas shiner	*Notropis amabilis* (Girard)
Rosefin shiner	*Notropis ardens* (Cope)
Emerald shiner	*Notropis atherinoides* Rafinesque

(Continued)

Cyprinidae (continued)

Bigeye shiner	Notropis boops Gilbert
Striped shiner	Notropis chrysocephalus (Rafinesque)
Common shiner	Notropis cornutus (Mitchill)
Whitetail shiner	Notropis galacturus (Cope)
Blackchin shiner	Notropis heterodon (Cope)
Spottail shiner	Notropis hudsonius (Clinton)
Red shiner	Notropis lutrensis (Baird and Girard)
Silver shiner	Notropis photogenis (Cope)
Duskystripe shiner	Notropis pilsbryi Fowler
Rosyface shiner	Notropis rubellus (Agassiz)
Spotfin shiner	Notropis spilopterus (Cope)
Sand shiner	Notropis stramineus (Cope)
Telescope shiner	Notropis telescopus (Cope)
Redfin shiner	Notropis umbratilis (Girard)
Blacktail shiner	Notropis venustus (Girard)
Mimic shiner	Notropis volucellus (Cope)
Suckermouth minnow	Phenacobius mirabilis (Girard)
Southern redbelly dace	Phoxinus erythrogaster (Rafinesque)
Bluntnose minnow	Pimephales notatus (Rafinesque)
Fathead minnow	Pimephales promelas Rafinesque
Bullhead minnow	Pimephales vigilax (Baird and Girard)
Colorado squawfish	Ptychocheilus lucius Girard
Northern squawfish	Ptychocheilus oregonensis (Richardson)
Blacknose dace	Rhinichthys atratulus (Hermann)
Longnose dace	Rhinichthys cataractae (Valenciennes)
Speckled dace	Rhinichthys osculus (Girard)
Redside shiner	Richardsonius balteatus (Richardson)
Creek chub	Semotilus atromaculatus (Mitchill)

Catostomidae

River carpsucker	Carpiodes carpio (Rafinesque)
Quillback	Carpiodes cyprinus (Lesueur)
Longnose sucker	Catostomus catostomus (Forster)
White sucker	Catostomus commersoni (Lacépède)
Bluehead sucker	Catostomus discobolus Cope
Flannelmouth sucker	Catostomus latipinnis Baird and Girard
Largescale sucker	Catostomus macrocheilus Girard
Mountain sucker	Catostomus platyrhynchus (Cope)
Blue sucker	Cycleptus elongatus (Lesueur)
Northern hog sucker	Hypentelium nigricans (Lesueur)
Smallmouth buffalo	Ictiobus bubalus (Rafinesque)
Bigmouth buffalo	Ictiobus cyprinellus (Valenciennes)
Black buffalo	Ictiobus niger (Rafinesque)

(Continued)

Catostomidae (continued)

Spotted sucker	*Minytrema melanops* (Rafinesque)
Silver redhorse	*Moxostoma anisurum* (Rafinesque)
River redhorse	*Moxostoma carinatum* (Cope)
Gray redhorse	*Moxostoma congestum* (Baird and Girard)
Black redhorse	*Moxostoma duquesnei* (Lesueur)
Golden redhorse	*Moxostoma erythrurum* (Rafinesque)
Shorthead redhorse	*Moxostoma macrolepidotum* (Lesueur)
Humpback sucker	*Xyrauchen texanus* (Abbott)

Ictaluridae

White catfish	*Ictalurus catus* (Linnaeus)
Blue catfish	*Ictalurus furcatus* (Lesueur)
Black bullhead	*Ictalurus melas* (Rafinesque)
Yellow bullhead	*Ictalurus natalis* (Lesueur)
Brown bullhead	*Ictalurus nebulosus* (Lesueur)
Channel catfish	*Ictalurus punctatus* (Rafinesque)
Slender madtom	*Noturus exilis* Nelson
Stonecat	*Noturus flavus* Rafinesque
Tadpole madtom	*Noturus gyrinus* (Mitchill)
Brindled madtom	*Noturus miurus* Jordan
Freckled madtom	*Noturus nocturnus* Jordan and Gilbert
Flathead catfish	*Pylodictis olivaris* (Rafinesque)

Percichthyidae

White bass	*Morone chrysops* (Rafinesque)
Yellow bass	*Morone mississippiensis* Jordan and Eigenmann
Striped bass	*Morone saxatilis* (Walbaum)

Centrarchidae

Rock bass	*Ambloplites rupestris* (Rafinesque)
Green sunfish	*Lepomis cyanellus* Rafinesque
Orangespotted sunfish	*Lepomis humilis* (Girard)
Bluegill	*Lepomis macrochirus* Rafinesque
Longear sunfish	*Lepomis megalotis* (Rafinesque)
Redear sunfish	*Leopmis microlophus* (Günther)
Smallmouth bass	*Micropterus dolomieui* Lacépède
Spotted bass	*Micropterus punctulatus* (Rafinesque)
Largemouth bass	*Micropterus salmoides* (Lacépède)
White crappie	*Pomoxis annularis* Rafinesque
Black crappie	*Pomoxis nigromaculatus* (Lesueur)

(Continued)

Percidae

Greenside darter	Etheostoma blennioides Rafinesque
Rainbow darter	Etheostoma caeruleum Storer
Fantail darter	Etheostoma flabellare Rafinesque
Johnny darter	Etheostoma nigrum Rafinesque
Tessellated darter	Etheostoma olmstedi Storer
Orangethroat darter	Etheostoma spectabile (Agassiz)
Banded darter	Etheostoma zonale (Cope)
Yellow perch	Perca flavescens (Mitchill)
Logperch	Percina caprodes (Rafinesque)
Gilt darter	Percina evides (Jordan and Copeland)
Blackside darter	Percina maculata (Girard)
Sauger	Stizostedion canadense (Smith)
Walleye	Stizostedion vitreum vitreum (Mitchill)

Sciaenidae

Freshwater drum	Aplodinotus grunniens Rafinesque

Cottidae

Mottled sculpin	Cottus bairdi Girard
Piute sculpin	Cottus beldingi Eigenmann and Eigenmann
Banded sculpin	Cottus carolinae (Gill)

Part II: Fishes from European Tailwaters

Salmonidae	
Baltic salmon	*Salmo salar* Linnaeus
Cyprinidae	
Zope	*Abramis ballerus* (Linnaeus)
Bream	*Abramis brama* (Linnaeus)
Golden shiner (European)	*Abramis* sp.
Bystryanka	*Alburnoides bipunctatus* (Bloch)
Bleak	*Alburnus alburnus* (Linnaeus)
Barbel	*Barbus barbus* (Linnaeus)
White bream	*Blicca bjoerkna* (Linnaeus)
Shemaia	*Chalcalburnus chalcoides* (Güldenstädt)
Nase (Podust)	*Chondrostoma nasus* (Linnaeus)
Carp	*Cyprinus carpio* Linnaeus
Gudgeon	*Gobio gobio* (Linnaeus)
Ide	*Leuciscus idus* (Linnaeus)
Roach or Vobla	*Rutilus rutilus* (Linnaeus)
Khramulya	*Varicorhinus capoëta* (Güldenstädt)
Vimba	*Vimba vimba* (Linnaeus)
Percidae	
Volga pike-perch	*Lucioperca volgensis* (Gmelin)
Cottidae	
Common bullhead (sculpin)	*Cottus gobio* Linnaeus

APPENDIX D: LIFE HISTORY INFORMATION FOR THE MOST COMMON FISH GROUPS MENTIONED IN THE TEXT

Table D1

Fish Groups, General Characteristics

Fish group, occurrence	Category (forage, F; *game*, G; rough, R)	Life span years	First maturity Age years	First maturity Length mm	Preferences Habitat	Preferences Temperature °C	Preferences Water clarity
Gizzard shad							
Rivers, lakes, and reservoirs; most found eastern U.S.	F	4-6	2-3	250-350	Pools, backwaters	22-24	No preference
Trout							
Rivers, lakes, and reservoirs; common throughout U.S.	G	3-5	2-4	250-380	Riffles, pools	10-15	Clear
Carp							
Rivers, lakes, and reservoirs; common throughout U.S.	R	5-6	2-4	300-450	Backwater pools	20-22	Turbid
Suckers							
Rivers, lakes, and reservoirs; various species found throughout U.S.	R	5-6	2-4	300-400	Pools and riffles	14-20	Clear to turbid

(Continued)

(Sheet 1 of 3)

Table D1 (Continued)

Fish group, occurrence	Category (forage, F; game, G; rough, R	Life span years	First maturity Age years	Length mm	Preferences Habitat	Temperature °C	Water clarity
Channel catfish							
Most common in large rivers but also found in some reservoirs; introduced throughout the U.S.	G	6-10	4-6	330-560	Deep pools	27-30	Semiturbid
White bass							
Lakes, rivers, and reservoirs; introduced throughout the U.S.	G	4-6	2-3	250-300	Deep pools	23-25	Clear
Black basses*							
Found throughout the U.S. in lakes, reservoirs, and rivers	G	4-7	3-4	250-320	Pools	21-27	Clear

(Continued)

*Three species are common--largemouth, smallmouth, and spotted--and each has different requirements.

(Sheet 2 of 3)

Table D1 (Continued)

Fish group, occurrence	Category (forage, F; game, G; rough, R)	Life span years	First maturity		Preferences		
			Age years	Length mm	Habitat	Temperature °C	Water clarity
Sunfishes							
Lakes, rivers, and reservoirs; most common eastern two-thirds U.S.	F,G	3-4	2-3	100-150	Pools	22-25	Clear to turbid
Crappies							
Lakes, rivers, and reservoirs; most common eastern half U.S.	F,G	3-4	2-3	150-200	Pools	22-24	Clear to slightly turbid
Walleye							
Lakes, rivers, and reservoirs; most common eastern half U.S.	G	5-7	3-4	350-450	Open water, pools	18-21	Clear

(Sheet 3 of 3)

Table D2

Fish Groups, Spawning and Eating Characteristics

	Spawning				Food		
Fish group	Season	Temperature °C	Location	Incubation period days	Young	Adults	Remarks
Gizzard shad	Spring, early	17-23	Shallow, protected areas (scattered)	4	Plankton	Plankton	Young common in tailwaters during fall and winter; important forage.
Trout	Winter, spring	4-16	Riffle (nest)	20-80	Plankton	Insects, fish	The rainbow is the most common trout stocked in cold tailwaters.
Carp	Spring, early summer	17-20	Flooded shallows (scattered)	4-8	Plankton	Insects, plant material	Adaptable to many habitats; considered a nuisance because of destructive habits.
Suckers	Late winter, spring	13-23	Shoal areas (scattered)	4-14	Plankton	Insects, algae	About 12 species of suckers, including *redhorse* suckers, occur in tailwaters; life history varies by species.

(Sheet 1 of 3)

(Continued)

Table D2 (Continued)

Fish group	Spawning				Food		Remarks
	Season	Temperature °C	Location	Incubation period days	Young	Adults	
Channel catfish	Late spring, early summer	24-29	Natural cavaties (nest)	5-10	Plankton, insects	Insects, fish	Highly sought as food fish, particularly southeastern U.S.
White bass	Spring, early summer	14-21	Midwater over hard bottom (scattered)	2	Plankton	Insects, fish	Important tail-water sport fish in spring and summer.
Black basses	Spring, early summer	16-18	Sand-gravel (nest)	2-4	Plankton, insects	Insects, fish	Important sport fish. Small-mouth and spotted basses most common in streams; large-mouth in lakes.
Sunfishes	Spring, early summer	20-22	Firm bottom (nest)	3-5	Plankton	Insects	Important sport fishes. Blue-gill, green and longear sun-fishes most common in tailwaters.

(Continued)

(Sheet 2 of 3)

Table D2 (Continued)

	Spawning				Food		
Fish group	Season	Temperature °C	Location	Incubation period days	Young	Adults	Remarks
Crappies	Spring	16-20	Firm bottom (nest)	3	Plankton, insects	Insects, fish	Important sport fishes. Adults may be common in tailwaters during spring and young during fall and winter.
Walleye	Spring	6-8	Gravel, rubble (scattered)	12-18	Plankton, insects	Fish	Important sport fish in tailwaters of some large rivers.

(Sheet 3 of 3)

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APPENDIX E: GLOSSARY

Algae: primitive plants, one-celled to many-celled.

Allochthonous: materials such as leaves and detritus that originate from outside a lake or stream.

Amphipods: group of crustaceans that includes the freshwater forms Hyalella and Gammarus.

Anadromous fish: fish that spend most of their lives in the sea or lakes but ascend rivers to spawn.

Anaerobic organisms: microorganisms that thrive in the absence of oxygen.

Annelids: earthworms and leeches.

Anoxia: state of having too little oxygen in tissues for normal metabolism.

Arachnids: spiders and water mites.

Armoring: accumulation of coarse particles on a stream bottom through loss of finer materials to the current; the formation of a firm layer on the streambed that is resistant to further degradation.

Arthropods: group of invertebrate animals that includes crustaceans, insects, and spiders.

Autochthonous: materials such as algae, macrophytes, and their decomposition products that originate within a lake or stream.

Autotrophy: type of nutrition in which an organism manufactures its own food from inorganic compounds.

Benthic organisms (benthos): aquatic invertebrates such as mollusks, immature aquatic insects, and crustaceans that live on or in the stream bottom.

Biomass: total weight of a particular species or of all organisms in a particular habitat.

Biota: all living organisms in a region.

Bryozoans: small bottom organisms that make up part of the benthos.

Carnivore: any animal partly or wholly dependent on catching other animals for its food.

Chironomids: family of insects of the Order Diptera; large group that includes the nonbiting, mosquitolike midges.

Cladocerans: freshwater crustaceans; includes such zooplankton genera as Daphnia, Chydorus, and Alona.

Copepods: freshwater crustaceans; includes such zooplankton genera as *Diaptomus* and *Cyclops*.

Crustaceans: includes certain zooplankters (copepods and cladocerans), amphipods, decapods, isopods, and ostracods.

Daphnids: any member of the cladoceran genus *Daphnia*.

Decapods: freshwater shrimp and crayfish.

Detritivores: organisms that ingest detritus.

Detritus: fine particulate debris of organic or inorganic origin.

Diatoms: class of algae having silicified skeletons.

Dipterans: order of insects that includes true flies.

Drift: aquatic or terrestrial invertebrates that move or float with the current.

Ecology: science of the interrelations between living organisms and their environment.

Encystment: formation of a resistant cyst by certain microorganisms, especially under unfavorable environmental conditions.

Ephemeropterans: order of insects that includes the mayflies.

Epilimnion: upper stratum of more or less uniformly warm circulating water that forms in lakes and reservoirs during periods of stratification and extends from the surface to the metalimnion or thermocline.

Excystment: portion of the life cycle of an organism when it emerges from its cyst stage and resumes normal metabolic activity.

Fingerling: immature fish, from a length of about 25 mm (or size at disappearance of yolk sac) to the end of first year of life.

Fry: life stage of fish between hatching of the egg and assumption of adult characteristics (usually at a length of about 25 mm).

Gastropods: snails.

Habitat: place where a particular plant or animal lives.

Herbivore: organism that feeds on plant material.

Heterotrophy: type of nutrition in which an organism depends on organic matter for food.

Hydraulic residence time: time (usually days) required for a volume of water equal to the reservoir capacity to move through the reservoir and be discharged downstream.

Hypolimnion: lower stratum of cold and relatively undisturbed water that forms in lakes and reservoirs during periods of stratification and extends from the bottom up to the metalimnion or thermocline.

Instar: any one of the successive stages in the life history of an insect.

Isopods: freshwater crustaceans (Asellus), which are similar to terrestrial sow bugs.

Laminar flow: smooth, low-velocity flow, with parallel layers of water shearing over one another, and with little or no mixing of layers.

Lentic: standing waters such as lakes and ponds.

Lepidopterans: order of insects that includes the moths and butterflies.

Limnology: study of the physical, chemical, and biological conditions in fresh waters.

Lotic: running waters such as streams and rivers.

Macrophytes: macroscopic or large forms of vegetation.

Metalimnion: stratum between the epilimnion and the hypolimnion in stratified lakes and reservoirs; exhibits marked thermal discontinuity; temperature changes at least 1°C per metre throughout this stratum.

Mollusks: soft-bodied animals usually enclosed in a shell and having a muscular foot; freshwater forms include snails and clams.

Nymphs: one of a series of immature stages in certain insects.

Oligochaetes: earthworms and their aquatic representatives.

Omnivore: any animal that eats a variety of living and dead plants and animals.

Ostracods: small crustaceans enclosed in bivalve shells; resemble small clams.

Periphyton: association of aquatic organisms attached or clinging to stems and leaves of rooted plants or other surfaces projecting above the stream bottom.

pH: the negative logarithm of the effective hydrogen-ion concentration. Used to express both acidity and basicity on a scale of 0 to 14; 7 represents neutrality, numbers less than 7 increasing acidity, and numbers greater than 7 increasing basicity.

Photosynthesis: complex of processes involved in the formation of carbohydrates from carbon dioxide and water in living plants in the presence of light and chlorophyll.

Phytoplankton: small plants (algae) that live unattached in the water.

Piscivorous: feeding on fishes.

Plankton: organisms of relatively small size, mostly microscopic, that drift with the water current; some have weak powers of locomotion.

Plecopterans: order of insects that includes the stoneflies and salmonflies.

Pool: portion of a stream that is deep and quiet relative to the main current.

Redd: type of fish spawning area (usually a cleared circular or oblong depression) in running water with a gravel bottom.

Redox potential: oxidation-reduction potential; a measure of the oxidizing or reducing intensity of a solution.

Riffle: shallow rapids in an open stream, where the water surface is broken into waves by obstructions wholly or partly submerged.

Run: stretch of relatively deep, fast-flowing water with the surface essentially nonturbulent.

Seston: living or nonliving bodies of plants or animals that float or swim in the water.

Simuliids: family of insects of the Order Diptera; includes black flies and buffalo gnats.

Spate: a sudden freshet or flood.

Stenothermal: refers to an organism that can maintain itself only over a relatively narrow range of temperature.

Stratification: separation of and nonmixing between the surface epilimnetic water and the deep hypolimnetic water because of density differences between the two layers.

Tailwater: channel or stream below a dam.

Thermocline: see metalimnion.

Trichopterans: order of insects that includes caddisflies.

Trophic level: refers to the position occupied by an organism in a simplified food chain.

Turbellarians: free-living flatworms.

Turbidity: cloudiness of water caused by the presence of suspended matter.

Turbulent flow: flow with secondary, heterogeneous eddies superimposed on the main forward flow, accompanied by considerable mixing of components.

Water quality: a term used to describe the chemical, physical, and biological characteristics of water in respect to its suitability for a particular use.

Zooplankton: animal microorganisms that live unattached in the water.

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  Walburg ... [et al.]. (East Central Reservoir
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  Experiment Station). -- Vicksburg, Miss. : U.S. Army
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